DEVELOPMENT OF KNOWLEDGE SYSTEM FOR LANDING GEAR DESIGN WITH OPTIMIZED LEG

by

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DEPARTMENT OF AERONAUTICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

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DEVELOPMENT OF KNOWLEDGE SYSTEM FOR LANDING GEAR DESIGN WITH OPTIMIZED LEG

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by
SUNIL VASANT KOLHE

to the

DEPARTMENT OF AERONAUTICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY, KANPUR

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CERTIFICATE

This is to certify that the work entitled 'Development of knowledge system for landing gear design with optimized leg' by Sunil Vasant Kolhe has been carried out under my supervision and has not been submitted elsewhere for the award of a degree.

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ABSTRACT

A knowledge system for the design of aircraft landing gear with optimized leg has been developed. The system has high degree of flexibility which helps the user in comparative study of the design with slight changes in parameters. It may be used as a teaching aid for beginner and an effective tool for an experienced designer.

The knowledge system works on the basis of logic programming. The predicate calculus used is horn clauses. The knowledgebase of the system consist of landing gear design processes coded into 'if-then' rules.

The design details that has been coded into the database are, tyre design, detailed wheel analysis and design, landing leg analysis and optimal weight design, and brake design. It incorporates procedures used for the selection of, type of landing gear, tyre pressure, type of landing leg, shock absorber, and brake system.

It is possible to get a design details for any type of requirement without designing the landing gear completely, after the system has generated experience of designing many landing gear.

NOMENCLATURE

a	Internal diameter of web-frame
A_b	Cross sectional area of tie bolt
A_{BF}, A_{CE}, A_{ED}	Cross sectional area of braces BF, CE and ED
b	External diameter of web-frame
D	Outside diameter of tyre
d	Wheel rim diameter
D_L	Dynamic load on each leg
d_1, d_2	External and internal diameter of tubular section of leg.
E	Young's modulus of elasticity of leg material
F_{TB}	Total outward bursting force
F_{TH}	Flange thickness
F_1, F_2	Drag forces acting on leg
H	Height between point B and D (Fig. 3.3a)
H_L	Total height of leg
H_{LA}	Length of link-B (Fig. 3.3a)
H_{LB}	Length of link C (Fig. 3.3a)
H_1, H_2	Height between points B and C, and points C and A (Fig. 3.3a)
I	Moment of inertia of leg section
I_r	Moment of inertia of unit length area of web-frame, equation (3.12)
J_S	Jack stroke
L_1	Length of member CD (Fig. 3.3a)
M	Moment per unit length, equation (3.11)
M_1	Moment due to eccentricity of resultant of uniform tyre pressure

N_b	Number of bolts
p_{FT}	Final tyre pressure
p_o, p_1	External and internal axial pressure on web-frame
p_2, p_3	Intensity of uniform side force, at external and internal diameter of web frame
p_4, p_5	Intensity of pure torque at external and internal diameter of web frame
Q	Side force
q	Exponent in exterior penalty function method
r	Tyre section radius
r_1	Any radius at which stresses are to be calculated
R_{B_1}, R_{B_2}	Reactions at point B
R_{BH_1}, R_{BH_2}	Horizontal reactions at point B
R_{BV_1}, R_{BV_2}	Vertical reactions at point B
R_{CX_1}, R_{CX_2}	Horizontal reactions at point C
R_{D_1}, R_{D_2}	Reactions at point D
r_k	Penalty parameter
R_w	Wheel rim width
t	Thickness of web-frame
w_1	Distance between joints B and D (Fig. 3.3a)
w_2	Distance between joints B and C (Fig. 3.3b)
w_2	Distance between joints C and D (Fig. 3.3b)
x_1, x_2	Variables of exterior penalty function method (External and internal diameter of leg section)
γ	Poisson's ratio
ρ	Density of material used for leg

ω	Rotational velocity of wheel
σ_{bd}	Safe working stress in tie bolt
$\sigma_{cc}, \sigma_{cc_1}, \sigma c_1, \sigma_{c_2}, \sigma_{c_b}$	Compressive stresses in leg
σ_f	Safe working stress in flange
$\sigma_{r_1}, \sigma_{r_2}, \sigma_{r_3}, \sigma_{r_1}', \sigma_{r_2}', \sigma_{r_3}'$	Radial stresses in web-frame
$\sigma_{\theta_1}, \sigma_{\theta_2}$	Tangential stresses in web-frame
$\sigma_{rmc}, \sigma_{rmt}$	Maximum radial, compressive and tensile stress in web-frame
$\sigma_{\theta mt}$	Maximum tangential tensile stress in web-frame
$\sigma_{r\theta_1}, \sigma_{r\theta_2}$	Shear stresses due to pure torque in web-frame
σ_{rz}	Shear stress due to side force in web-frame
$\sigma_{tc}, \sigma_{tb}, \sigma_{tc_1}, \sigma_{t_1}, \sigma_{t_2}$	Tensile stresses in leg
τ_1, τ_2	Shear stresses in leg
$\Delta A_x, \Delta A_{x_1}$	Deflection of leg in x-direction
ΔA_z	Deflection of leg in z-direction
θ	Angle made by web with vertical (Fig. 3.2c)
θ_1	Angle made by brace E_D with vertical (Fig. 3.3b)
θ_2	Angle made by brace B_F with vertical (Fig. 3.3b)

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CHAPTER - 1

INTRODUCTION

1.1 Landing gear design

The landing gear represents a substantial unit of modern aircrafts. It accounts for 3.5 to 5 percent of gross weight of the aircraft or 15 to 20 percent of its structural weight.[1] Though, contribution of undercarriage to flying and economy of aircraft is virtually nothing, when the aircraft is not flying its function is much more important than any other part of the structure.

The purpose of undercarriage is to perform the following major functions during ground-run of aircraft :

(i) to taxi or roll up to its take-off position, and away from its landing run ;

(ii) at the moment of landing, to observe its direction of motion, from a downward glide to a horizontal run along the runway ;

(iii) to carry its own means of retarding forward motion, or braking, without resort to external arresting equipment ;

(iv) to provide an accelerating run for take-off ;

(v) and to absorb the shock when taxying over a rough track

Undercarriage unit consists of, tyres, wheels, brakes, landing legs and associated retraction equipments. This system should withstand all or some of the following loads[2] : high vertical load, drag load, side load, and anti-drag load. There are different stressing cases, with combination of above mentioned loads, which are discussed in the following chapters.

Aeroplane wheels themselves present few fundamental problem to the landing gear designer. To enable the tyres to be fitted and removed, wheels are usually of split or detachable rim type[1], the old fashioned well-base rim, which is still used on road vehicle, being rare on modern aero-wheels. Several large modern aircrafts are making use of double-tyred wheels. An important problem in design of modern high-speed aircrafts is accomodation of brake of adequate energy absorption capacity inside the wheel.

Landing leg may be of articulated type or telescopic type; former being heavier, less used in practice. Use of articulated layout in main and nose legs is unusual, it is virtually standardised for tail wheels. Telescopic layouts are: braced twin legs, cantilever with offset wheel, cantilever with fork, twin wheels, inclined wheel, inclined leg and offset twin wheels. Articulated leg layouts are, levered type with fixed shock absorber, levered type with hinged shock absorber, tension shock absorber and articulated bogie landing layout.

The retraction of landing leg is virtually universal on all but light or slow aircrafts.[1] The determination of the optimum retraction method and mechanism involves, firstly, problem of geometry and secondly design of radius rods, actuators and up and down locks. The basic linkage from which nearly all solutions are derived is the well-known four bar linkage (fig. 1.1), where the outer links A and C rotate, link B is floating and airframe forms the forth link. Fig. 1.2 shows the classic solution, where, the shock absorber leg is the rotating link A with the links B and C forming the folding stays.

1.2 Literature survey

The most remarkable fact is that, in spite of an ever increasing strength requirement, the percentage weight of the landing gear has gone down[3] in the last fifteen years. Improved techniques in design and in the use of new materials has made it possible which shows that a lot of work has been done in undercarriage design area, but comparatively less matter appears in literature. The few available are discussed here.

Conway H.G.[1] gives general arrangement of the landing gear, details of tyre design, general details of wheels, brakes, shock absorbers and retraction. He also gives general layout of the landing gear and landing gear stressing. Smith[4], compared different types of wheels and also gives the performance of the components of a wheel. He emphasizes more on testing and proving requirements.

The problem of shimmy of airplane wheels is particularly important in case of tricycle type landing gear.[5] In a tricycle type of landing gears, the wheel fitted with tyre is designed to pivot freely about a vertical axis and when in action this pivot is given a horizontal forward motion, while the wheel is made to roll on ground. It happens that the wheel spontaneously assumes a self-sustained oscillating motion about the pivot. A full scale investigation has been conducted to determine the effect of various factors on shimmy of castoring wheels[6], the factors considered being the geometric arrangement, the tyre types, the variation of load, the spindle moment of inertia, and the tyre inflation.

Flugge, considers effect of landing impact and taxying impact on landing gear.[7]

Arun Kumar[8], has developed expert system for design of undercarriage which helps user in comparative study of design with slight changes in design parameter. It gives design details like, tyre and brake design. It also incorporates the procedure for selection of type of landing gear, outer dimensions of wheels, tyre pressure, braking system and shock absorber. This expert system does not give a detailed design of wheel, brake, shock absorber and landing leg. It also lacks in giving a procedure for the selection of retraction method and mechanism.

Study of existing literature, thus reveals the following salient features :

- Hardly any attempt has been made to achieve a detailed design of wheel of the aircraft.
- Any recent work on landing leg design, shock absorber design, and retraction was not found.
- Hardly any attempt has been reported to perform optimal weight design of any part of landing gear.

The purpose of the present thesis is to attempt to fill some of the existing gaps as far as possible.

1.3 Present work

The present work is divided into two parts. The first part of the thesis deals with the detailed design of wheel, procedure for selection of retraction method and mechanism, and design of landing leg and its accessories. The wheel is designed as modern split type A-frame wheel, which is mostly used in modern aircrafts. The retraction mechanism used is as shown in fig. 1.2.

Low weight is of prime importance in aircraft structures. The second part of the thesis is dedicated to perform optimal weight design of landing leg. Results have been obtained for different types of landing leg, viz : Retractable landing gear, unretractable braced landing gear and unretractable unbraced landing gear.

In overall, an attempt has been made to have a complete design of undercarriage system, so that designer(s) will have all the required design dimensions of landing gear. While designing, comparative studies will have to be undertaken. Since, generally it is found that, all likely configurations cannot be transferred into fully developed projects. This requirement is fulfilled by developing a highly flexible program , which helps user in comparative study of the design with slight changes in parameters. More details about program developed, is given in chapter 2.

Use has been made of available program of Arun Kumar, which supplies necessary parameters for design requirements.

1.4 Thesis layout

The general layout of the thesis is presented below. Chapter 2, explains, the tool used in the programming. Analysis and design procedure for wheel and landing leg, procedure for selection of retraction method and mechanism and, method of optimization used for optimal weight design of landing leg is explained in chapter 3. Discussion regarding implementation is given in chapter 4. Chapter 5, presents the discussion of results and conclusion and also putsforth suggestion for future work.

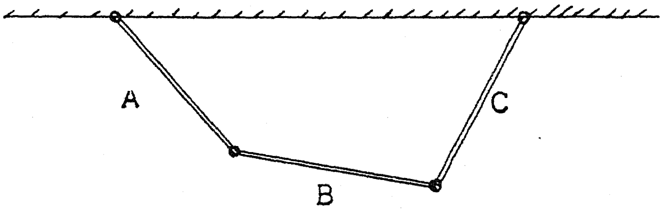
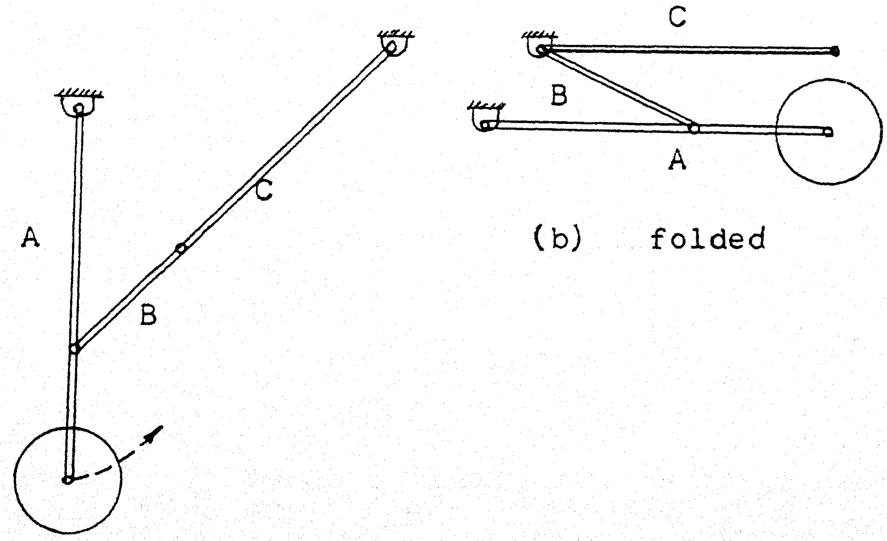


Fig. 1.1 : BASIC RETRACTION MECHANISM



(a) Unfolded

(b) folded

Fig. 1.2 : CLASSIC SOLUTION - LEG ROTATES

CHAPTER 2

TOOL USED FOR PROGRAMMING

This section briefly describes the tool used for programming.

2.1 Artificial intelligence (A.I.)

A.I.[9] is a software technique that programs use to solve symbolic rather than numeric problems, symbolic problems, which are problems encountered in common every day life and work, deal with symbols and symbolic concepts rather than numbers.

A.I. systems fall into three basic categories[10]: expert (or knowledge-base) systems, natural language (every day native language) systems, and perception systems for vision, speech, and touch.

2.2 Expert systems

Expert systems are programs that use humanlike reasoning processes rather than complicated techniques to solve problems in specific problem domains.[11] These programmed, human like reasoning processes, in turn rely on experimental human knowledge, which is encoded in the program in structure called knowledge-base (fig. 2.1).

In an expert system, the knowledge base is the encoded knowledge of an expert expressed as a large set of rules, facts, together with a set of assertions. It uses an inference technique which works on knowledge domain and arrives at conclusion. In this process it acquires the relevant required details of problem through questions asked to user.

Typically, to build an expert system, the developer chooses a form to represent the experts knowledge. The developer then encodes some of the experts basic knowledge and reasoning techniques in that form. Then the developer challanges that expert system with lot of problems and cases. As the fledging expert system makes mistakes or provides insufficient data, its developer add more knowledge and thus improves on the model of the expert. (Fig. 2.2).

In engineering, expert systems can be effectively used. It can be an effective tool for an experienced designer, and may be used as a teaching aid for beginners.

2.3 vidur : the interpreter

In any expert system the knowledge about the domain in which the system works, must be separate from how that knowledge is to be infered or applied. Expert systems consist of two major components :

1. a knowledge base
2. an interpreter

In present work an interpreter, also called a shell, is named as VIDHI[13], developed based on logic programming by Dr. R. Sangal of Computer Science and Engg. Department of I.I.T. Kanpur. The programming language used in VIDHI is CLISP.

2.3.1 Logic programming

a. Introduction

Logic programming used in VIDHI is based on a subset of first order predicate calculus namely the horn clauses[14]. It is used for solving problems involving objects and relationships. To express relation between objects, predicates are used. For example, to express that the colour of eye is blue :

COLOUR (EYE, BLUE)

COLOUR is the predicate, which is 2-place predicate. It can also be represented in list notation as follows,

(COLOUR EYE BLUE)

In VIDHI latter type is used.

b. Pattern matching

The representation of knowledge can be divided into two types :

(i) Pattern which can have zero or more occurrence of wild card.

(ii) A data item or a fact which does not have a wild card, where a wild card is a variable which can take any value. For example,

1. (COLOUR EYE BLUE)
2. (COLOUR HAIR BLACK)

are some examples of facts. Here COLOUR is a predicate which has two arguments. Similarly, if we have wild card in place of arguments, like

3. (COLOUR ?X BLUE)
4. (COLOUR HAIR ?Y)
5. (COLOUR ?X ?Y)

then these are called as patterns. When patterns and facts match, we get value for wild card provided the name of the predicate is same and non-wild card arguments in pattern and fact is same. In above case when fact 1 is matched with pattern 3 we get -

?X = EYE

whereas if we match fact 2 with pattern 3 the matching will fail, since second argument is different. Pattern 5 can be matched to both the facts 1 and 2. In logic programming the pattern matching concept can be utilized successfully.

c. Formulas

In VIDHI[13], two types of objects are defined, terms and formulas. Terms occur as arguments of predicates in formulas and usually denote things. A formula on the other hand takes a truth value.

A term is one of the following :

(i) a variable :- a symbolic atom beginning with a '?' (e.g., ?X, ?COLOUR).

(ii) a constant :- a symbolic atom not beginning with a '?' (e.g., 3, 5.6, BLUE).

(iii) a function-argument combination :- a list of the form

$(\langle f \rangle\ \langle p_1 \rangle\ \text{----}\ \langle p_n \rangle)$

where $\langle f \rangle$ is a function symbol and $\langle p_1 \rangle$ to $\langle p_n \rangle$ are arguments. For example,

(AVERAGE L M N)

where AVERAGE is a function followed by its three arguments.

A formula takes any one of the following two forms :

(i) An atomic formula is a predicate-arguments combination :- where predicate is a symbolic atom, and arguments are terms. It is represented as list. For example,

(COLOUR EYE BLUE)

(ii) A horn clause (formula) is of the form

$$R < - S_1 \text{ --- } S_n \qquad n > = 0 \qquad \text{---} \qquad (1)$$

where R and S_1 to S_n are atomic formulas. R is called consequent, and S_1 to S_n are called the antecedent. If the antecedent is empty, it reduces to an atomic formula.For example,

```
(CHECK-STRESS ?TY) < - (STRESS-PRED ?TY ?SIR)
                       (GEO-PRED ?TY ?THI)
```

Formulas takes truth values. For example, in formula (1), R is true whenever each member S_1 to S_n is true.

d. Inference

Inference allows us to infer new facts from the database. When a query is floated, it is checked with facts, if it is there, the query is answered true. If matching with facts fails, then matching with the LHS of rules are tried. If a rule matches, the atomic formulas in its RHS after proper instantiation become the new sub-goals, and same procedure as above is repeated. In case of failure to match a subgoal, another rule will be tried. This process repeats until either we are successful, or no more rules remain to be tried. For example,

```
1. (CHECK-STRESS A3 NOSE-WHEEL 1500)
2. (CHECK-STRESS A4 TAIL-WHEEL 2100)
3. (CHECK-STRESS ?AA ?TY ?WT) < - (WT-AC ?AA ?WT)
                                  (TY-AC ?AA ?TY ?WT)
4. (WT-AC A1 2500)
5. (WT-AC A2 3000)
6. (TY-AC A1 TAIL-WHEEL 2500)
```

Now, if we pose the query -

```
GOAL (CHECK-STRESS A1 ?TY 2500)
```

since no fact matches it will try on rules. Here, rule 3 is tried.

```
    (CHECK-STRESS A1 ?TY 2500)
           < - (WT-AC A1 2500)
               (TY-AC A1 ?TY 2500)
```

the antecedents become new sub-goals.

```
    SUB-GOAL (WT-AC A1 2500)
```

is true.

```
    SUB-GOAL (TY-AC  A1 ?TY 2500)
```

is also true and ?TY = TAIL-WHEEL

Therefore, the main goal is true and ?TY = TAIL-WHEEL is returned.

2.3.2 <u>User-level tools of VIDHI</u>

a. Adding facts and rules[14]

Any one of the following forms can be used.

```
    (DEFASRT   <NAME>  <FORMULA>)
    (DEFASSERT <NAME> <FORMULA>)
```

For example,

```
(DEFASRT F1 (CHECK-STRESS A1 TAIL-WHEEL 2500))
(DEFASRT R1 (CHECK-STRESS ?AA ?TY ?WT)
          < - (WT-AC ?AA ?WT)
              (TY-AC ?AA ?TY ?WT))
```

Similarly for removing facts and rules any one of following can be used

```
    (UNDEFASRT <NAME> <FORMULA>)
    (UNDEFASSERT <NAME> <FORMULA>)
```

b. Querying the database

Following form is used for querying

(GOAL <a_1> ---- <a_n>)

where a_1 to a_n are atomic formulas

c. Posing questions

Questions can be posed using a built-in predicate called ASK-USER.

(ASK-USER (SOURCE <Var 1> --- <var n>)
(TARGET <var 1> --- <var m>)
(QUESTION . . . .)
(TYPES < ty 1> --- <ty n>))

For ASK-USER, predicate to be true, the following conditions must have to be satisfied.

- all source variables should have values assigned.
- all target variables should be value free. Failure to satisfy either of the above conditions makes ASK-USER fail.

d. Defelaboration

It is used to explain to the user, when the user responds with a 'WHAT' to a question.

(DEFELAB <Pred> (<text>))

A text is stored with the predicate pred to do the job.

e. Defcomputepred

It declares that the predicate is of computational type.

(DEFCOMP <pred> <LAMBDA EXPRESSION>)

Inside the lambda expression computations are done or another function can be called. The values computed can be asserted into database using ASSERTA command.

For details VIDHI manual can be referred. Apart from the above tools, any CLISP functions can also be used in VIDHI.

2.4 Features of the program developed

Some of the features of the program developed are mentioned below

(i) Solves or helps to solve important problems that would otherwise require the service of human expert.

(ii) Integrate new knowledge incremently into the knowledge base.

(iii) Display knowledge in form that is easy for people to read.

(iv) High degree of flexibility, that is, when user presents weight and the purpose of the aircraft, he is provided with a design without any further details requiring from him, this is done because of earlier experience of the program. If no design has been done under that category the user will be so informed and the program starts new design. If user is satisfied with the present available design, he can retain the same. If he wishes to see if there are any other designs under same category, he can do so. If he wishes to alter any one of available designs by changing one or all the design parameters, that can also be achieved. It may be noted that this is the feature most of the aircraft designers would like to have, which would provide them a means of comparative study. If he wishes to have new design altogether, then it can also be done. Fig. 2.3, explains this, and working of the program more clearly.

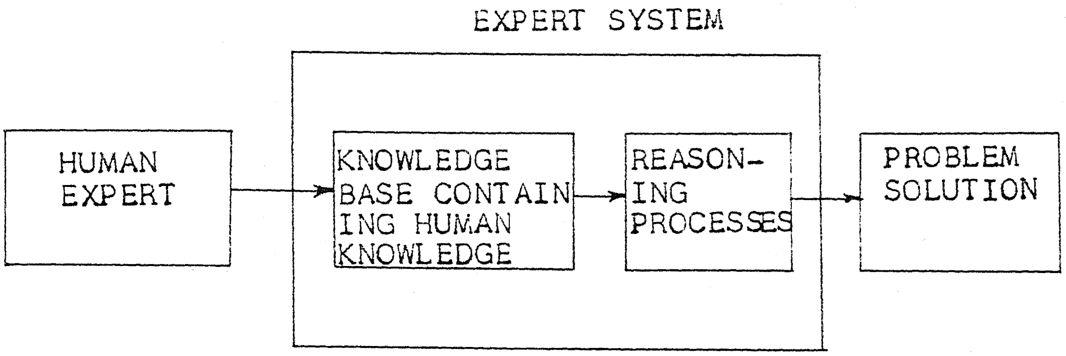


Fig. 2.1 : EXPERT SYSTEMS SOLVE PROBLEMS BY REASONING WITH KNOWLEDGE ACQUIRED FROM HUMAN EXPERT.

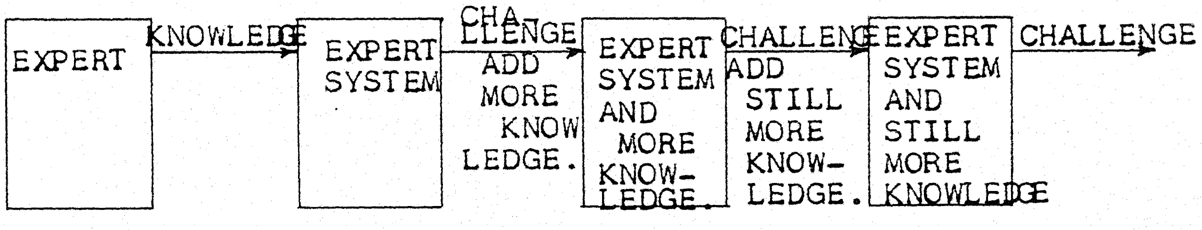

EXPERT
KNOWLEDGE
EXPERT SYSTEM
CHALLENGE
ADD MORE KNOWLEDGE.
EXPERT SYSTEM AND MORE KNOWLEDGE.
CHALLENGE
ADD STILL MORE KNOWLEDGE.
EXPERT SYSTEM AND STILL MORE KNOWLEDGE
CHALLENGE

Fig. 2.2 : EXPERT SYSTEM DEVELOPMENT

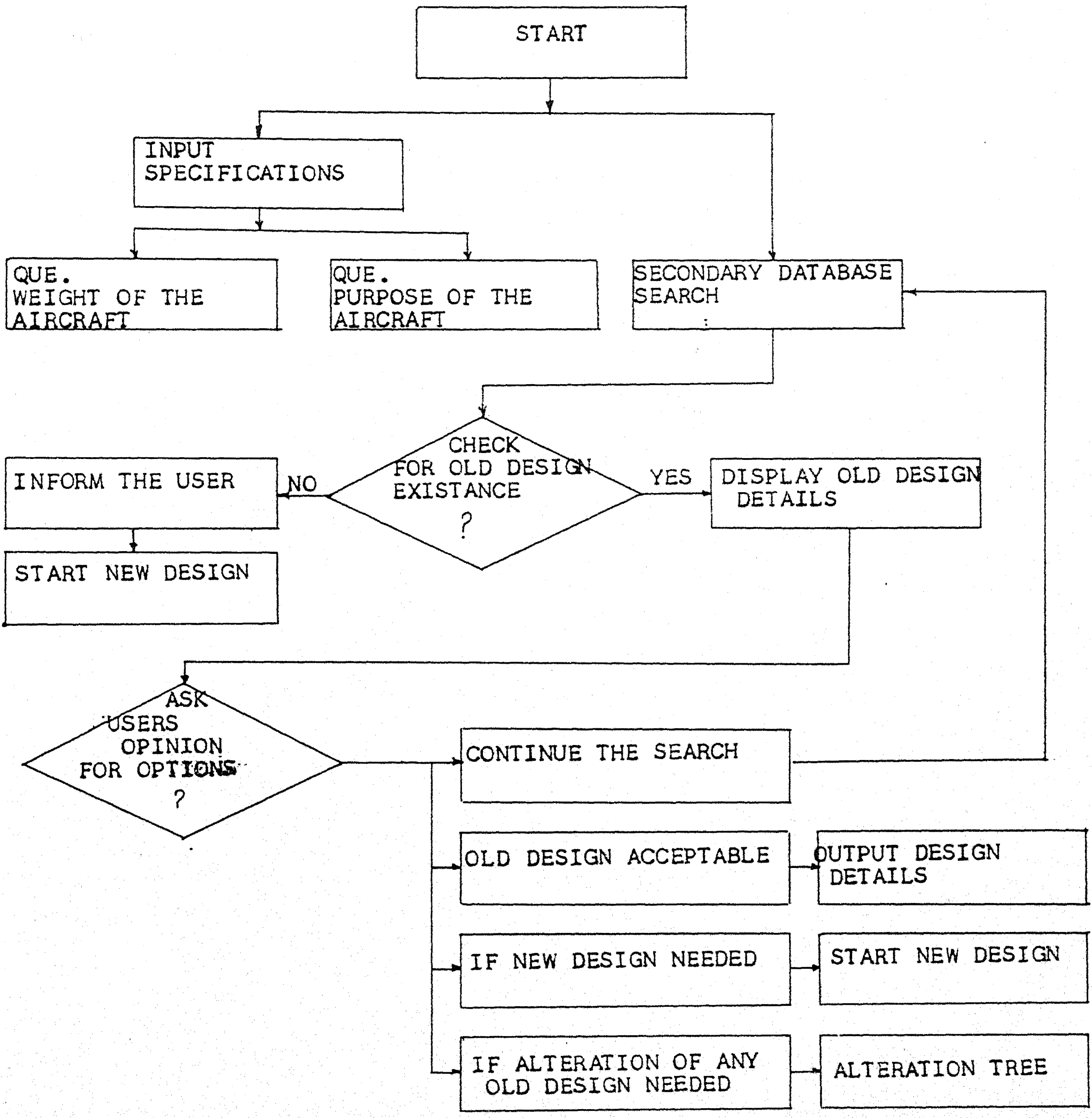

START
INPUT SPECIFICATIONS
QUE. WEIGHT OF THE AIRCRAFT
QUE. PURPOSE OF THE AIRCRAFT
SECONDARY DATABASE SEARCH
CHECK FOR OLD DESIGN EXISTANCE ?
NO
YES
INFORM THE USER
START NEW DESIGN
DISPLAY OLD DESIGN DETAILS
ASK USERS OPINION FOR OPTIONS ?
CONTINUE THE SEARCH
OLD DESIGN ACCEPTABLE
OUTPUT DESIGN DETAILS
IF NEW DESIGN NEEDED
START NEW DESIGN
IF ALTERATION OF ANY OLD DESIGN NEEDED
ALTERATION TREE

Fig. 2.3 : FLOW CHART FOR MAIN FRAME

CHAPTER 3

ANALYSIS AND DESIGN DETAILS

3.1 Introduction

Present chapter includes analysis and design details of aircraf wheel, retraction method and mechanism, and landing leg. It gives details of method used for performing optimal weight design of landing leg and analysis of braces. Miscellaneous details like, jack stroke, design of tie bolts for wheel are also explained in the following paragraphs.

3.2 Wheel analysis and design

It is important to keep the weight of any aircraft components down to an absolute minimum for economic reasons. In respect of the wheel, only a small percentage of its life is spent doing useful work.[15] For the majority of its time on the aircraft, the wheel is stowed and ferried as 'dead weight'. It is only during takeoff/landing and taxying of the aircraft that the wheel serves its useful purpose. The main and nose wheels are part of the load supporting structure of the aircraft. The wheel not only carries the tyre, forming a pressure vessel with the wheel, but in case of the main wheel also houses the brake. There are two basic designs of aircraft wheel, 'A' frame and 'bowl' type[4]. The 'A' frame wheel is structurally very efficient, and therefore the lightest that can be achieved. However, this design only provides limited space for the brake, and when a large brake is required, it is necessary to resort to a 'bowl' type configuration, which, being structurally less efficient is by necessity heavier.

The 'A' frame wheel being structurally more efficient and lighter, is adopted here. The 'A' frame wheel design (fig.3.1) consist of two half hubs butted together and secured by a ring of circumferentially spaced bolts. The brake is housed within the half hub.

The different forces acting on wheel and other structures of landing gear are; high vertical load, normal drag , side force , high drag , force arising due to braking, etc. Intensity of these forces as per British Airworthiness requirement is[2]

- Normal drag - > 0.4 (maximum vertical reaction)
- side force - > 0.25(maximum vertical reaction)
- high drag - > 0.8 (maximum vertical reaction)

Intensity of force arising due to application of brake is slightly lesser than high drag, so if design is satisfied for high drag, it will be safe against this force.

Design of the tie bolts

The bolts are torque tightened not only to provide a good clamping joint, which will not separate under the most severe load conditions, but also to enhance the fatigue life of the bolts.

Usually material used for manufacturing of bolts is open-hearth nickel steel SAE 3140[10], whose elastic limit is 68,000 Psi. Same material is adopted here. For the diameter of bolt not less than 1 inch, factor of safety is usually 2.0. But for present situation diameter of bolt may hardly exceed 1/2 inch, so the design stress should be lowered. Therefore, considering factor of safety as 4.0, the design stress will be,

$$\sigma_{bd} = 17{,}000.0 \text{ Psi}$$

To find the number of bolts and diameter of bolt the total outward bursting force is used -

$$F_{TB} = \pi . p_{FT} . r \left(\frac{D^2 - d^2}{4 . r} - (D - r) \right) \quad \ldots \quad (3.1)$$

Also,

$$A_b = \frac{F_{TB}}{\sigma_{db} \times N_b} \quad \ldots \quad (3.2)$$

Number of bolts to be used are fixed using circumference of the wheel.

Wheel analysis

For the design of wheel flange thickness, total outward bursting force is used[1], as it produces the critical stresses in a flange. It is necessary to do the analysis for the web-frame portion only. Wheel rim diameter is fixed along with the tyre. When tyre is selected, the manufacturer's specification gives wheel rim diameter.

The forces acting on the web-frame portion are : the centrifugal force acting due to rotation of wheel, uniform compressive force due to uniform tyre-pressure, side force and, pure torque due to the drag load acting at tyre-ground contact.

The web-frame is analysed for all above forces simultaneously (fig. 3.2). Finally, point of action of maximum stresses and value of maximum stresses due to combined effect of all above forces will be found.

a. centrifugal force :

In this case web is analysed as rotating disc, assuming that web is straight, instead of being inclined. Stresses in web section can be found by following relation.[17]

$$\sigma_{r_1} = \left(\frac{3+\gamma}{8} \right) \rho\, \omega^2 \left[a^2 + b^2 - \frac{a^2b^2}{r_1^2} - r_1^2\right] \quad \ldots \qquad (3.3)$$

and

$$\sigma_{\theta_1} = \left(\frac{3+\gamma}{8} \right) \rho\, \omega^2 \left[a^2 + b^2 + \frac{a^2+b^2}{r_1^{\,2}} - \left(\frac{1+3\gamma}{3+\gamma} \right) r_1^{\,2} \right] \quad \ldots \qquad (3.4)$$

b. external and internal axial compressive force :

Here also, it is assumed that webs are straight, which is on the conservative side, as the stresses calculated will be higher than what it would be. Now it will be a case of thick cylinder with internal and external forces. Stresses can be calculated by the following relations.[18]

$$\sigma_{r_2} = \frac{a^2b^2\,(p_o - p_1)}{(b^2 - a^2)\,.\,r_1^{\,2}} + \frac{p_1a^2 - p_ob^2}{b^2 - a^2} \quad \ldots \qquad (3.5)$$

and

$$\sigma_{\theta_2} = \frac{-a^2b^2\,(p_o - p_1)}{(b^2 - a^2).r_1^{\,2}} + \frac{p_1a^2 - p_ob^2}{b^2 - a^2} \qquad \ldots \qquad (3.6)$$

The intensity of pressures p_o and p_1 are given by the relations :

$$p_o = \frac{p_{FT} \times R_w}{2 \times t} \qquad \ldots \qquad (3.7)$$

and

$$p_1 = \frac{p_o \times b}{a} \qquad \ldots \qquad (3.8)$$

Here, thickness 't' is assumed to be equal to thickness of flange.

c. side force :

In this case, side force and the moment, due to eccentricity of resultant of uniform tyre pressure, are considered (fig. 3.2c).

Intensity of the uniform side force and moment per unit length can be calculated by -

p_2 = side force/circumference

$$p_2 = \frac{0.25 \times DL}{2.\pi \times b} \qquad \ldots \qquad (3.9)$$

$$M_1 = \frac{R_w}{6} \times (p_o \times 2\,t) \qquad \ldots \qquad (3.10)$$

The intensity of total moment per unit length about the bearing level A-A can be calculated by -

$$M = M_1 + \frac{(2\pi \times b)\; p_2\,(b - a)}{2\times\pi \times a}$$

$$\therefore \quad M = \frac{R_w}{6} \times (p_o \times 2t) + \frac{b}{a}\, p_2\,(b-a) \qquad \ldots \qquad (3.11)$$

Second moment of unit length area about vertical axis will be -

$$I_r = 2 \left[t \quad (\cos \theta) \quad \left(\frac{R_w}{3}\right)^2 \right] \qquad \ldots \qquad (3.12)$$

Therefore, radial stress at radius 'a' can be expressed as -

$$\sigma_{r_3} = \frac{\frac{R_w}{6} (p_o \cdot 2t) + \frac{b}{a} p_2 (b-a)}{2. \left[t(\cos \theta) \cdot \left(\frac{R_w}{3}\right)^2\right]} \cdot \left[\frac{R_w}{3} + \frac{t \cos \theta}{2} \right] \ldots (3.13)$$

and

$$\sigma_{r_z} = p_2 \left(\frac{b}{a} \right) \left(\frac{1}{2 \cdot t \cos \theta} \right) \qquad \ldots \qquad (3.14)$$

d. drag force :

This force will act as pure torque on web-frame, producing the shear stress σ_{r_θ} . Intensity of this torque on external and internal face can be found by the relations -

$$p_4 = \text{drag force/circumference}$$

$$\therefore \quad p_4 = (0.4 \cdot DL) / (2 \cdot \pi \cdot b) \qquad \ldots \qquad (3.15)$$

and

$$p_5 = (0.4 \cdot DL) / (2 \cdot \pi \cdot a)$$

Maximum intensity of the shear stress σ_{r_θ} produced by the torque will be at inner most radius.

$$\sigma_{r_{\theta_1}} = \frac{p_5}{t} \qquad \ldots \qquad (3.16)$$

e. maximum radial stress :

The centrifugal force will produce maximum radial tensile stress at radius $\sqrt{ab}$[16]. Whereas external and internal compressive axial forces will produce maximum radial compressive stress at radius 'a'. Similarly, side force and a moment due to eccentricity of tyre pressure will produce maximum tensile and compressive force in right and left web respectively, at radius 'a'

From the above discussion it is clear that, there are two different points, where tensile and compressives stresses are maximum. Tensile stress will be maximum at radius $\sqrt{ab}$. Compressive stress will be maximum at radius 'a'.

Intensity of maximum radial compressive stress can be found by following relation -,

$$\sigma_{rm_c} = p_1 + \sigma_{r_3} \qquad \ldots \qquad (3.17)$$

Radial stress due to centrifugal force at radius $\sqrt{ab}$ will be -

$$\sigma_{r_1}' = \left(\frac{3+\gamma}{8} \right) \rho \, \omega^2 \, [a-b]^2 \qquad \ldots \qquad (3.18)$$

Radial stress due to axial forces at radius $\sqrt{ab}$ will be -

$$\sigma_{r_2}' = \frac{ab \, (p_o - p_1)}{(b^2 - a^2)} + \frac{p_1 \, a^2 - p_o \, b^2}{(b^2 - a^2)} \qquad \ldots \qquad (3.19)$$

and

Radial stress due to side force and moment at radius equal to $\sqrt{ab}$ will be -

$$\sigma_{r_3}' = \frac{\frac{R_w}{6} \, (p_o \times 2t) \; + p_2 . b . \left(\sqrt{\frac{b}{a}} - 1\right)}{2 \, t \cos \theta . \left(\frac{R_w}{3 \tan \theta} - \sqrt{ab}\right)^2} \times \left(\frac{R_w}{3 \tan \theta} - \sqrt{ab} + \frac{t . \cos \theta}{2} \right) \qquad \ldots \qquad (3.20)$$

Intensity of maximum radial tensile stress will be then,

$$\sigma_{rm_t} = \sigma_{r_1}' + \sigma_{r_2}' + \sigma_{r_3}' \qquad \ldots \qquad (3.21)$$

f. maximum circumferential stress :

It can be noted that, both centrifugal and axial force produces maximum circumferential tensile stress at radius equal to 'a'. Therefore, maximum circumferential stress can be found by the relation -

$$\sigma_{\theta_{m_t}} = 2 \left(\frac{3+\gamma}{8} \right) \rho \; \omega^2 \left[b^2 + a^2 \left(\frac{1-\gamma}{3+\gamma} \right) \right] + \frac{p_1 (a^2+b^2) - 2\, p_o\, b^2}{(b^2 - a^2)} \qquad \ldots \qquad (3.22)$$

Wheel design

As already mentioned, for the design of wheel flange thickness, total outward bursting force is used (eq. 3.1), also we have

$$\frac{F_{TB}}{\pi d t} = \sigma_f$$

Since the wheels are mostly made up of aluminium alloy castings, the σ_f value can be taken in range of 18000-24000 psi, And, adopting factor of safety as 1.5,

Flange thickness

$$F_{TH} = \frac{1.5\, F_{TB}}{\pi\, d\, 18000} \qquad \ldots \qquad (3.23)$$

While designing, necessarily designer should consider economy in construction cost, there are several ways in which one can achieve this economy. Here also, if flange and web thickness is same it can be casted easily and economically. To achieve this, thickness of web is assumed to be equal to thickness of flange initially. Stresses are found using this thickness (eq. 3.14, 3.16, 3.17, 3.21, 3.22).

If the stresses calculated are within the limits, that is, lesser than safe working stress, which is taken in range of 18000-24000 psi, the web thickness is kept equal to thickness of flange. Otherwise, increasing thickness step by step and checking the stresses simultaneously, web thickness is redesigned.

Different forces acting on the wheel are already mentioned. The worst combinations of forces are[1] -

i) Normal drag and side load,

ii) High drag only, and

iii) Loads arising from applying the brake

Loads arising due to application of brake is almost equal to the second combination. The stresses calculated before are for the first combination. Now, designed thickness of the web should also be tested for high drag force, which acts as pure torque on web-frame. Maximum intensity of torque due to this drag, at radius equal to 'a'.

$$p_5 = \frac{0.8\ DL}{\pi . a}$$

$$\therefore \sigma_{r\theta_2} = \frac{p_5}{t} \qquad \ldots \qquad (3.24)$$

If above calculated shear stress stress is greater than the safe working stress, web thickness will be redesigned.

3.3 Retraction method and mechanism

Incorporating many kinds of engineering in its design and construction, modern landing gear has advanced to the stage in which almost any aircraft[15], but light or slow aircraft, can be supplied with rectractable configuration, which can be stowed in a space. Retraction and extension of the gear is normally done by hydraulic power. A hydraulic system consists of a number of individual items connected by piping and it is obviously much easier to alter the power of, say, a hydraulic jack than an electric actuator.

The well-known four-bar linkage (fig. 1.) from which nearly all solutions to retraction are derived, consist of two rotating links[1], one floating link and airframe as fourth link. Various configurations of the retraction linkage is possible. The one which is adopted here is the classic solution (fig. 1.2), where shock absorber leg is the rotating link, and other two links forms radius rod or folding stay. To achieve an retraction and extension of the landing gear hydraulic jack with two locks can be used, which saves unnecessary complications due to separate up and down locks.

It is proposed to consider 10,000 lb as the limit between lig and heavy aircrafts, so that landing gear of aircraft having weight lesser than 10,000 lb will be designed as unretractable, and for the aircraft weighing greater than or equal to 10,000 lb, it is designed as retractable.

Kinematics (geometry)

Once the mechanism of retraction is fixed, then comes the problem of geometry or kinematics. Fig. 3.3a shows geometry in detail. The angle between shock-absorber leg and radius rod is kept usually in range 45°-60°. The height of shock-absorber section (H_2) is fixed according to shock absorber travel, which is usually limited to 15 inches as the maximum limit. Once these values are fixed, the total length of radius rod including link B and C can be easily found as -

$$L_1 = \frac{(H_L - H_2 + H)}{\sin 45} \qquad \ldots \qquad (3.25)$$

Value of H is found from outer radius of tyre, usually it is kept as outer radius of tyre plus some margin in the range of 3-6 inches.

Now, from geometrical analysis, length of link-B and link-C is found as -

$$H_{LA} = \left[\left(\frac{(H_L - H_2)^2 - H^2}{2(H_L - H_2)} \right)^2 + H^2 \right]^{1/2} \qquad \ldots \qquad (3.26)$$

and

$$H_{LB} = L_1 - H_{LA} \qquad \ldots \qquad (3.27)$$

Jack stroke can be found by simple geometrical calculations -

$$J_s = (H_L - H_2) + H - H_{LA} \cdot \sin 45 \qquad \ldots \qquad (3.28)$$

3.4 Leg analysis

A decision must now be made, whether landing leg layout is to be telescopic or articulated[1]. Decision must be taken, whether it is to be a cantilever leg, braced twin leg or cantilever with force. Telescopic leg layout, being lighter, will be adopted here. For simplicity in design, cantilever with offset wheel type telescopic leg layout is adopted in cases where the number of tyres in wheel is only one. Twin wheel type telescopic layout in cases of two or more tyres in wheel will be adopted.

As mentioned in wheel design, there are two worst landing combination, for which landing gear should be designed. First, normal drag with side force and second is, high drag load or loads arrived due to braking. Landing leg will be designed to sustain both the combinations.

Landing leg will be designed as retractable if the weight of aircraft is greater than or equal to 10,000 lb, otherwise it will be designed as unretractable type. In unretractable type, depending on the height of the leg, it will be designed as braced or unbraced type, to reduce the dimensions of section of the landing leg. If the height of leg is less than 3.0 feet it will be designed as unbraced type, otherwise braced type would be adopted. So, we have three type of landing leg, viz: Retractable, Unretractable-braced and Unretractable-unbraced. (Fig. 3.3).

Analysis of legs

a. Retractable type

It is assumed that the joint C is designed such, that it transfers only inplane (XY) moments, it does not transfer the moment due to side load. It is also assumed that joint E does not transform any load to the jack shaft, as the jack is not suppose to withstand the loads in extended position.

Condition 1> Normal drag + side load :

To find out reaction at D -

$\Sigma M = 0$ about B

$$F_1 \; (H_1 + H_2) = (R_{D_1} \sin 45) \; \omega_1 - (R_{D_1} \cos 45) . H$$

$$\therefore \; R_{D_1} = \frac{F_1 \; (H_1 + H_2)}{\sin 45 \; (\omega_1 - H)} \qquad \ldots \qquad (3.29)$$

$\Sigma H = 0$,

$$R_{BH_1} + F_1 = R_{D_1} \sin 45$$

$$\therefore \; R_{BH_1} = R_{D_1} \sin 45 - F_1 \qquad \ldots \qquad (3.30)$$

$\Sigma V = 0$,

$$R_{BV_1} = D_L - R_{D_1} \sin 45 \qquad \ldots \qquad (3.31)$$

One can see that maximum stresses may occur at point 'C' or Point 'B'.

Maximum compressive stress produced by loads may be one of the following.

$$\sigma_{cc} = \frac{32 \; d_1 \; H_2}{\pi \; (d_1^{\;4} - d_2^{\;4})} \; (F_1 + Q) + \frac{4 \; D_L}{\pi \; (d_1^{\;2} - d_2^{\;2})} \qquad \ldots \qquad (3.32)$$

$$\sigma_{cb} = \frac{32 \; Q \; (H_1 + H_2).d_1}{\pi \; (d_1^{\;4} - d_2^{\;4})} + \frac{4 \; D_L}{\pi \; (d_1^{\;2} - d_2^{\;2})}$$

Maximum tensile stress produced by loads may be one of the following.

$$\sigma_{tc} = \frac{32\ d_1\ H_2\ (F_1+Q)}{\pi\ (d_1^4 - d_2^4)} - \frac{4\ D_L}{\pi\ (d_1^2 - d_2^2)} \quad \ldots \quad (3.33)$$

$$\sigma_{tb} = \frac{32\ Q\ (H_1+H_2)\ d_1}{\pi\ (d_1^4 - d_2^4)} - \frac{4\ D_L}{\pi\ (d_1^2 - d_2^2)}$$

Maximum shear stress would be -

$$\tau_1 = \frac{4\ (Q^2 + F_1^2)^{1/2}}{\pi\ (d_1^2 - d_2^2)} \quad \ldots \quad (3.34)$$

Maximum deflection will occur at point 'A'. Here, member AB is analysed as a beam. The deflection caused by buckling is much smaller than the deflection due to transverse bending moment. Hence for deflection calculations, buckling effect is neglected.

Deflection at point 'A' (fig. 3.4a) is -

$$\Delta A_x = \frac{1}{3\ EI}\ (F_1 \cdot H_2^3) + \frac{R_{BH_1} . H_1^3}{3\ EI} \left(\frac{H_L}{(\omega_1 - H)} - 1 \right) \ldots \quad (3.35)$$

and

$$\Delta A_z = \frac{Q . H_L^3}{3\ EI} \quad \ldots \quad (3.36)$$

Condition 2> High drag only.

In this case -

$$R_{D_2} = \frac{F_2\ (H_1+H_2)}{\sin 45\ (\omega_1 - H)}$$

$$R_{BH_2} = R_{D_2} \sin 45 - F_2 \quad \ldots \quad (3.37)$$

$$R_{BV_2} = D_L - R_{D_2} \sin 45$$

Maximum stresses will occur at point 'C',

$$\therefore \left.\begin{aligned} \sigma_{cc_1} &= \frac{32\, d_1 . F_2 . H_2}{\pi\,(d_1^{\,4} - d_2^{\,4})} + \frac{4\, D_L}{\pi\,(d_1^{\,2} - d_2^{\,2})} \\ \sigma_{tc_1} &= \frac{32\, d_1\, F_2\, H_2}{\pi\,(d_1^{\,4} - d_2^{\,4})} - \frac{4\, D_L}{\pi\,(d_1^{\,2} - d_2^{\,2})} \\ \text{and} \qquad & \\ \tau_2 &= \frac{4\, F_2}{\pi\,(d_1^{\,2} - d_2^{\,2})} \end{aligned}\right] \quad \ldots \quad (3.38)$$

Similarly,

Deflection at Point A will be (fig. 3.4a),

$$\Delta A_{x1} = \frac{1}{3\,EI}\,(F_2 . H_2^{\,3}) + \frac{R_{BH_2} . H_1^{\,3}}{3EI}\left(\frac{H_L}{(\omega_1 - H)} - 1\right) \quad \ldots \quad (3.39)$$

b. Unretractable-braced :

The joint 'C' is designed in such a way that it can take reactions in x and z direction, and is free to move in y direction to reduce the loads coming on main member 'AC'. It is assumed that joint E and F transfers the inplane (xy) moments only.

Condition 1> Normal drag + side load

To find out reaction at 'D'

$\Sigma M = 0$ about 'B'

$$(R_{D_1} \cos \theta_1)\,(\omega_2 + \omega_3) = D_L \cdot \omega_1 + F_1 . H_L$$

$$\therefore R_{D_1} = \frac{F_1 \cdot H_L + D_L\ \omega_1}{(\omega_2+\omega_3)\ \cos\theta_1} \qquad \ldots \qquad (3.40)$$

$\Sigma y = 0$

$$D_L + R_{B_1}\cos\theta_2 - R_{D_1}\cos\theta_1 = 0$$

$$R_{B_1} = \frac{R_{D_1}\cos\theta_1 - D_L}{\cos\theta_2} \qquad \ldots \qquad (3.41)$$

$\Sigma x = 0$

$$F_1 - R_{B_1}\sin\theta_2 - R_{D_1}\sin\theta_1 + R_{cx_1} = 0$$

$$\therefore R_{cx_1} = R_{B_1}\sin\theta_2 + R_{D_1}\sin\theta_1 - F_1 \qquad \ldots \qquad (3.42)$$

Maximum bending moment will occur at point 'E' and

$$= [F_1\ (H_2 + H_3) - (R_{B_1}\sin\theta_2)\ H_2]$$

Maximum compressive and tensile stresses will occur at point 'E'.

$$\sigma_{c_1} = \frac{32}{\pi}\ \frac{d_1}{(d_1^{\,4} - d_2^{\,4})}\ [\ F_1\ (H_2+H_3) - H_2\ (R_{B_1}\sin\theta_2) + Q\ (H_2 + H_3)\ ] + \frac{4\ (D_L + R_{B_1}\cos\theta_2)}{\pi\ (d_1^{\,2} - d_2^{\,2})} \qquad \ldots \qquad (3.43)$$

$$\sigma_{t_1} = \frac{32}{\pi}\ \frac{d_1}{(d_1^{\,4} - d_2^{\,4})}\ [F_1\ (H_2+H_3) - H_2\ (R_{B_1}\sin\theta_2) + Q\ (H_2+H_3)] - \frac{4\ (D_L + R_{B_1}\cos\theta_2)}{\pi\ (d_1^{\,2} - d_2^{\,2})}$$

Maximum shear stress ,

$$\tau_1 = \frac{4(Q^2+F_1^2)^{1/2}}{\pi\ (d_1^2-d_2^2)} \qquad \ldots \qquad (3.44)$$

Maximum deflection will occur at point, 'A' (Fig. 3.4b)

$$\left.\begin{aligned} \Delta A_x &= 0.32716\ \frac{F_1\ H_L^3}{EI} - \frac{R_{B_1}\ \sin\theta_2}{EI}\ (0.1759.\ H_L^3) \\ &\quad + 0.0154\ H_L^3\ .\ \frac{R_{cx_1}}{EI} \\ \Delta A_z &= \frac{Q\ H_L^3}{3\ EI} \end{aligned}\right] \qquad \ldots \qquad (3.45)$$

Condition 2> High drag only

Reactions will be,

$$\left.\begin{aligned} R_{D_2} &= \frac{F_2.H_L + D_L\cdot\omega_1}{(\omega_1+\omega_2)\ (\cos\theta_1} \\ R_{B_2} &= \frac{R_{D_2}\ \cos\theta_1 - D_L}{\cos\theta_2} \\ R_{cx_2} &= R_{B_2}\ \sin\theta_2 + R_{D_2}\ \sin\theta_1 - F_2 \end{aligned}\right] \qquad \ldots \qquad (3.46)$$

Maximum compressive and tensile stresses will be ,

$$\sigma_{c_2} = \frac{32}{\pi}\ .\ \frac{d_1}{(d_1^4 - d_2^4)}\ [\ F_2\ (H_2+H_3) - H_2\ (R_{B_2}\ \sin\theta_2)] + \frac{4\ (D_L + R_{B_2}\ \cos\theta_2)}{\pi\ (d_1^2 - d_2^2)} \qquad \ldots \qquad (3.47)$$

$$\sigma_{t_2} = \frac{32}{\pi} \frac{d_1}{(d_1^4 - d_2^4)} \left[F_2 (H_2 + H_3) - H_2 (R_{B_2} \sin \theta_2) \right] - \frac{4 (D_L + R_{B_2} \cos \theta_2)}{\pi (d_1^2 - d_2^2)}$$

Maximum shear stress

$$\tau_2 = \frac{4 F_2}{\pi (d_1^2 - d_2^2)} \qquad \ldots \qquad (3.48)$$

Maximum deflection (fig. 3.4b)

$$\Delta A_{x_1} = 0.32716 \frac{F_2 H_L^3}{EI} - \frac{R_{B_2} \sin \theta_2}{EI} (0.1759 H_L^3) + 0.0154 H_L^3 . \frac{R_{cx_2}}{EI} \qquad \ldots \qquad (3.49)$$

c. Unretractable-Unbraced :

Condition 1> Normal drag + side load:

Maximum compressive and tensile stresses will be at point 'B'

$$\sigma_{c_1} = \frac{32}{\pi} . \frac{d_1}{(d_1^4 - d_2^4)} (F_1 H_L + Q. H_L) + \frac{4 D_L}{\pi (d_1^2 - d_2^2)}$$

$$\sigma_{t_1} = \frac{32}{\pi} \frac{d_1}{(d_1^4 - d_2^4)} (F_1 H_L + Q H_L) - \frac{4 D_L}{\pi (d_1^2 - d_2^2)} \qquad \ldots \qquad (3.50)$$

maximum shear stress -

$$\tau_1 = \frac{4 F_1}{\pi (d_1^2 - d_2^2)} \qquad \ldots \qquad (3.51)$$

Maximum deflection will be - (fig. 3.4c)

$$\left.\begin{aligned} \Delta_x &= \frac{F_1\ H_L^{\ 3}}{3\ EI} \\ \Delta_z &= \frac{Q.H_L^3}{3\ EI} \end{aligned}\right] \qquad \ldots \qquad (3.52)$$

Condition 2> High drag only

Maximum stresses will be -

$$\left.\begin{aligned} \sigma_{c_2} &= \frac{32}{\pi} \cdot \frac{d_1\ F_2.H_L}{(d_1^{\ 4} - d_2^{\ 4})} + \frac{4\ D_L}{\pi\ (d_1^{\ 2} - d_2^{\ 2})} \\ \sigma_{t_2} &= \frac{32}{\pi} \cdot \frac{d_1\ F_2.\ H_L}{(d_1^{\ 4} - d_2^{\ 4})} - \frac{4\ D_L}{\pi\ (d_1^{\ 2} - d_2^{\ 2})} \\ \tau_2 &= \frac{4\ F_2}{\pi(d_1^{\ 2} - d_2^{\ 2})} \end{aligned}\right] \qquad \ldots \qquad (3.53)$$

maximum deflection will be (fig. 3.4c)

$$\Delta_{x_1} = \frac{F_2\ H_L^{\ 3}}{3\ EI} \qquad \ldots \qquad (3.54)$$

3.5 Optimization method and design

To perform optimal weight design of landing leg, Exterior Penalty function method is used. Penalty function methods transform the basic optimization problem into alternative formulations such that numerical solutions are sought by solving a sequence of unconstrained minimization problem.[20] In the exterior penalty function method, the Ø-function is generally taken as

$$\emptyset\ (x,\ r_k) = f(x) + r_k \sum_{j=1}^{m} <\ g_j\ (x)\ >^q$$

The bracket function $<\ g_j\ (x)\ >$ is defined as

$$<\ g_j\ (x)\ > = \max <\ g_j(x),\ o> = g_j(x) \text{ if } g_j(x) > 0$$

(constraint is violated)

$$0 \text{ if } g_j\ (x) \leq 0$$

(constraint is satisfied)

For unconstrained optimization Davidon-Fletcher-Powell method is used. This method is the best general purpose unconstrained optimization technique making use of derivatives that are currrntly available. Cubic interpolation method is used for single-variable optimization. Use is made of the Swans method to bracket the single variable optimal point.

Here, the Function, f(x) is same for all the three problems, viz : Retractable, Unretractable braced and Unretractable unbraced. It signifies the weight of the leg.

$$f(x) = \pi/4\ \rho\ H_L\ (d_1^{\,2} - d_2^{\,2})$$

$$f(x) = \pi/4\ \rho\ H_L\ (x_1^{\,2} - x_2^{\,2}) \qquad \ldots \qquad (3.55)$$

Constraints are different for all the three types of problems, following section gives constraints for these three sets

a. Retractable :

The constraint on geometry is that, thickness should not be less than 0.3 inch

$$- X_1 + X_2 + 0.2 \leqslant 0 \qquad \ldots \qquad (3.56)$$

The constraints due to the limiting stresses are -

$$M_{AX}\ (\sigma_{cc},\ \sigma_{cb},\ \sigma_{tc},\ \sigma_{tb},\ \sigma_{cc_1},\ \sigma_{tc_1}) - 24{,}000.0 \leq 0 \qquad \ldots \qquad (3.57)$$

and

$$M_{AX}\ (\tau_1,\ \tau_2) - 16{,}000.0 \leq 0 \qquad \ldots \qquad (3.58)$$

constraint due to deflection is

$$\left\{ [M_{AX}\ (\Delta A_x,\ \Delta A_z,\ \Delta A_{x_1})\ ] \div H_L \right\} - 0.01 \leq 0 \qquad \ldots \qquad (3.59)$$

b. Unretractable braced :

The constraint on geometry is same as in previous formulation

$$- X_1 + X_2 + 0.2 \leq 0 \qquad \ldots \qquad (3.60)$$

constraints due to limiting the stresses are -

$$M_{AX}\ (\sigma_{c_1},\ \sigma_{t_1},\ \sigma_{c_2},\ \sigma_{t_2}) - 24000.0 \leq 0 \qquad \ldots \qquad (3.61)$$

$$M_{AX}\ (\tau_1,\ \tau_2) - 16000.0 \leq 0 \qquad \ldots \qquad (3.62)$$

constraint due to deflection is

$$\left\{ [M_{AX}\ (\Delta A_x,\ \Delta A_z,\ \Delta A_{x_1})\ ] \div H_L \right\} - 0.01 \leq 0 \qquad \ldots \qquad (3.63)$$

c. Unconstrained unbraced :

The constraint on geometry as before

$$-X_1 + X_2 + 0.2 \leq 0 \qquad \ldots \qquad (3.64)$$

Constraints due to limiting the stresses is -

$$M_{AX}\ (\sigma_{c_1}, \sigma_{t_1}, \sigma_{c_2}, \sigma_{t_2}) - 24000.0 \leq 0 \quad \ldots \quad (3.65)$$

$$M_{AX}\ (\tau_1, \tau_2) - 16000.0 \leq 0 \quad \ldots \quad (3.66)$$

Constraint due to deflection is

$$\left\{ [M_{AX}\ (\Delta x, \Delta z, \Delta x_1)\ ] \div H_L \right\} - 0.01 \leq 0 \quad \ldots \quad (3.67)$$

3.6 Design of braces

The left side brace of unretractable braced type landing leg (fig. 3.4) is designed as tension member, as it mainly takes tension force only. The section of this member is kept hollow tubular. For simplicity in design, relation between internal and external diameter is fixed. Material used for leg and braces is usually Hot rolled steel tubes, taking design stress in range of 18,000-24,000 psi.

$$\therefore A_{bf} = \frac{R_{D_2}}{18{,}000.0} \quad \ldots \quad (3.68)$$

also,

$$A_{bf} = \pi/4\ (d_1^2 - d_2^2\ )$$

$$= \pi/4\ (d_1^2 - (1/2\ d_1)^2$$

$$A_{bf} = 0.589\ \ d_1^2 \quad \ldots \quad (3.69)$$

Other braces, as they mainly takes compressive force are designed as compression member. The design stress is varied according to the length of the member. As length of member increases slenderness ratio decreases, so for the member of greater length, design stress is reduced to 12,000.0 psi and should be able to sustain in buckling.

a. Design of brace CE :

It can be noted that length of this member is small. Therefore, keeping design stress as 18000.0 psi.

$$\left.\begin{array}{l} A_{CE} = \dfrac{R_{D_2}}{18000.0} \\ \text{and} \\ A_{CE} = 0.589 \ d_1^2 \end{array}\right] \qquad \ldots \qquad (3.70)$$

b. Design of brace ED :

Length of this member is larger, so taking design stress equal to 12,000.0 psi

$$A_{ED} = \frac{R_{D_2}}{12,000} \qquad \ldots \qquad (3.71)$$

Also taking, $d_2 = 0.667 \ d_1$

$$A_{ED} = 0.436 \ d_1{}^2 \qquad \ldots \qquad (3.72)$$

Design of brace DE in unretractable-braced type landing leg is done as for brace CE.

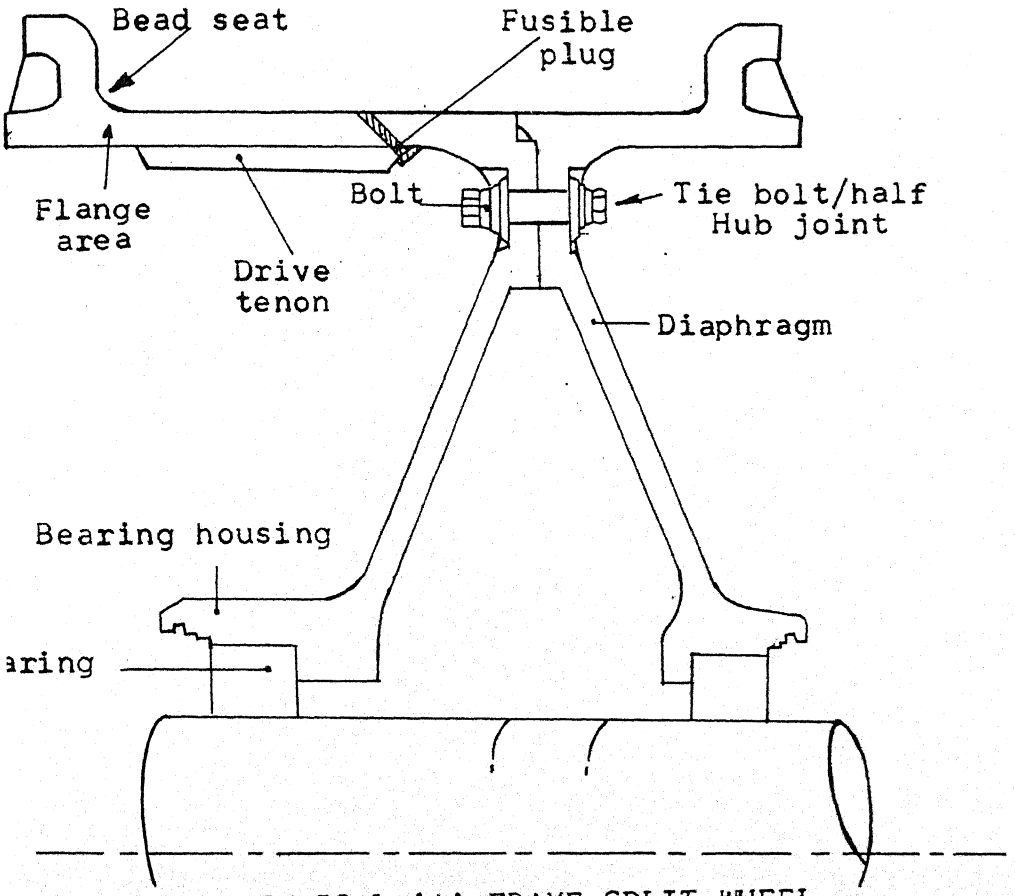
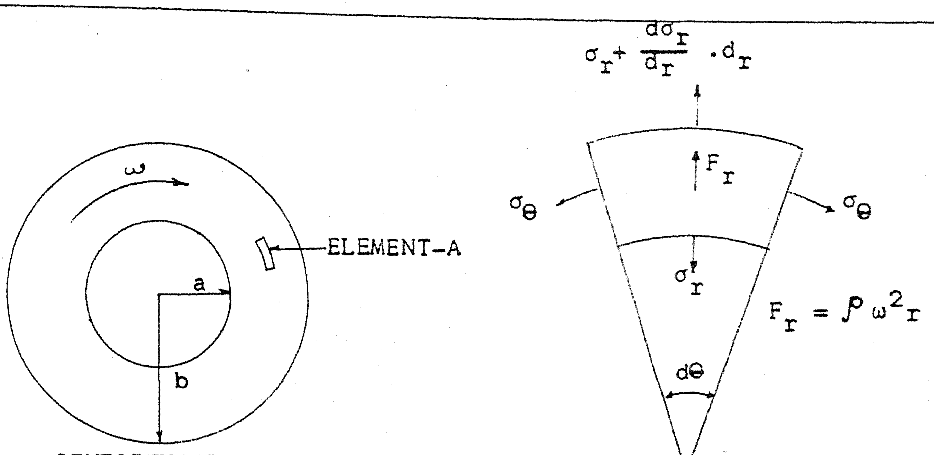
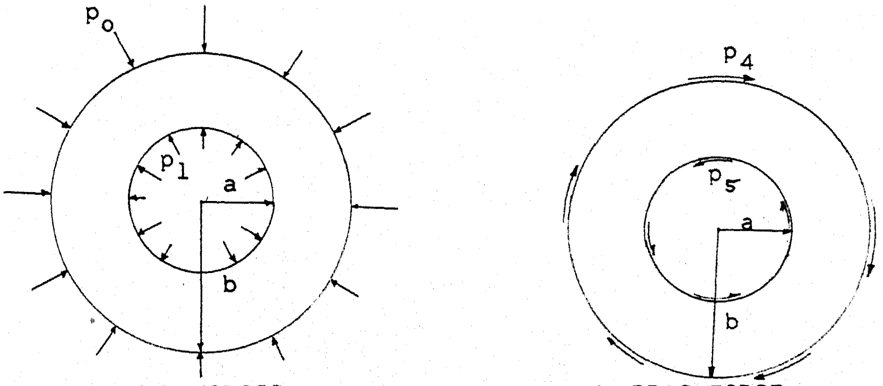


Fig. 3.1 : TYPICAL 'A' FRAME SPLIT WHEEL



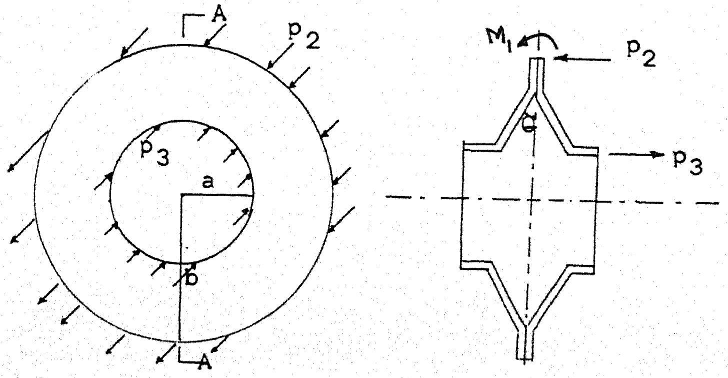
a. CENTRIFUGAL FORCE

FORCES ACTING ON ELEMENT-A



b. AXIAL FORCES

d. DRAG FORCE



c. SIDE FORCE

SECTION A-A

fig. 3.2 : DIFFERENT FORCES ACTING ON WHEEL WEB-FRAME

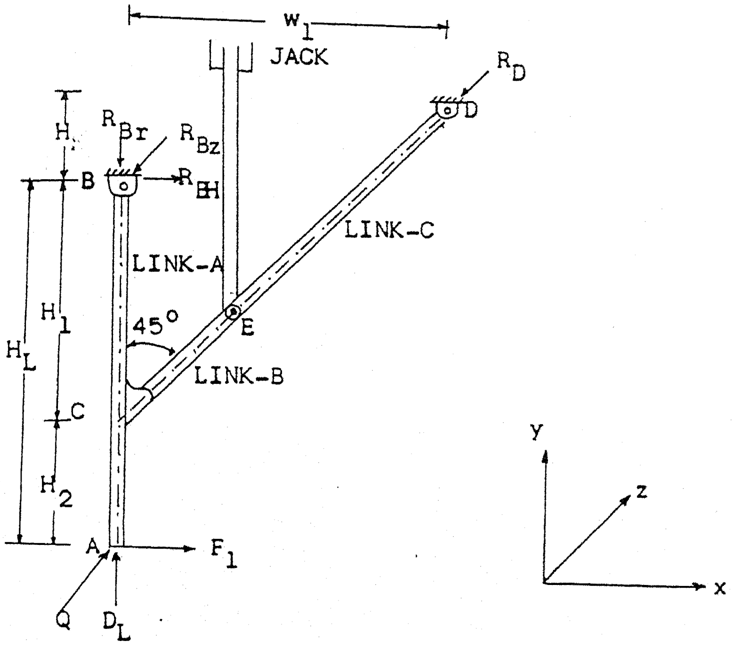


Fig. 3.3a : RETRACTABLE TYPE LANDING LEG.

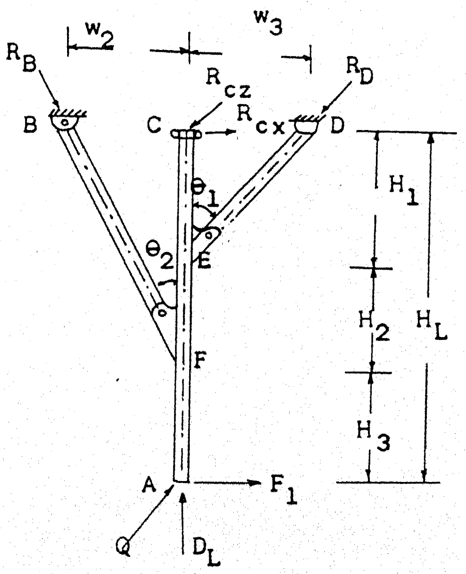


Fig.3.3b : UNRETRACTABLE BRACED TYPE LANDING GEAR

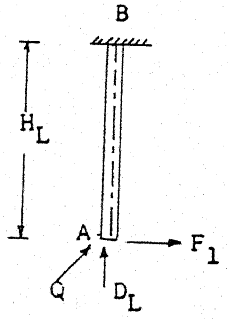
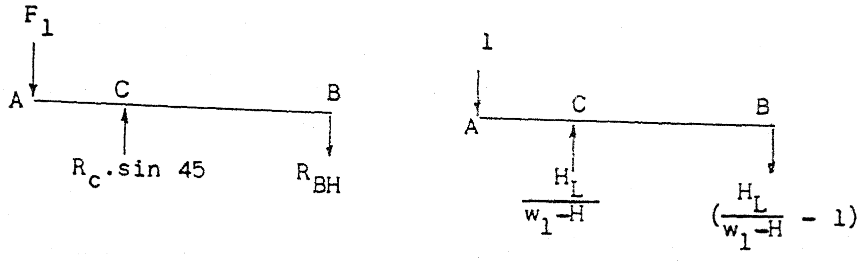
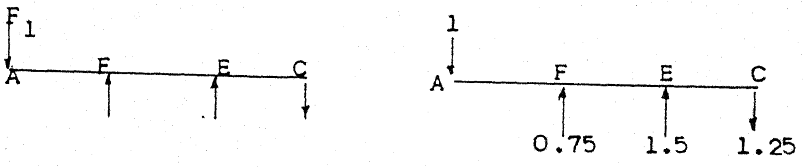


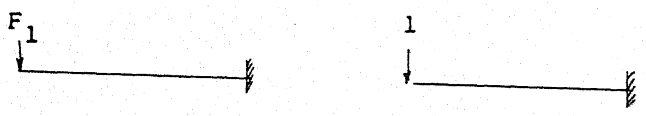
Fig.3.3C : UNRETRACTABLE UNBRACED TYPE LANDING GEAR.



a. RETRACTABLE TYPE LANDING LEG



b. UNRETRACTABLE-BRACED LANDING LEG



c. UNRETRACTABLE-UNBRACED LANDING LEG

Fig. 3.4 : DEFLECTION OF LANDING LEG.

CHAPTER 4

PROGRAM DESCRIPTION AND RULES

4.1 Introduction

It is essential for the user to know the structure of the program and how the design has been coded. The success of any expert system depends mainly on quantity and quality of knowledge it has in the knowledge base. As a result it is necessary to modify the knowledge base, with assistance from the user, to update it. To do so the user may add up new facts or rules or delete some. This chapter has been devoted to above objectives and also describes how to operate the system.

The program has been divided into three main branches. These are the main frame of the program, Design details tree, and Alteration tree. Main frame is the heart of the program, which controls flow according to users response. The design tree deals with the complete designing and optimizing part. The Alteration tree helps in altering the old design according to user requirement.

4.2 Main frame of the program

This part of the program gives outer structure of the Program. Fig. 2.3 explains it schematically.

When the user initiates the system with a query, GOAL (START), he enters the top most node in the tree which makes the program issue questions about two basic inputs, the weight of the aircraft for which the undercarriage has to be designed, and for what purpose aircraft would be used. Here, the purpose of aircrafts has been broadly put in ten groups to make design ~~simpler,~~ viz : Agriculture purpose, Light transport 1 to 4 seater, Trainer 1,2 seater, Executive transport 4 to 8 seaters, utility aircraft, light and amateur aircrafts, Fighters, Passengers and air service, cargo transport, sport planes.

Once user feeds this information, the Program starts searching the secondary database for the old design details. This is done by the rule 'SR1' which becomes a subquery -

```
(DEFASSERT SR1 (KNOWLEDGE BASE-SEARCH ?AA)
      < - (WEIGHT-RANGE ?WT-H ?WT-L)
          (STORAGE-PRED3 ?WEIGHT ?AA .... ?TY-BR)
          (< ? WEIGHT ?WT-H)
          (> ? WEIGHT ?WT-L)
          (OLD-DESIGN-DETAL-PRED ?WEIGHT ....?TY-BR)
          (USER-OPINION ?DUMMY ?OP ?N)
          (MODIFY-OLD-DESIGN ? WEIGHT ?OP ?DN))
```

Predicate 'STORAGE-PRED3' stores all old designs handled by the system. From these designs suitable designs are selected and checked to confirm whether it lies within reasonable limit of acceptance. Then that old design is displayed to user, this is done by the predicate 'OLD-DESIGN-DETAIL-PRED', and users opinion is asked - whether he wants to retain the same design or alter any one of the designs or continuing the search in database for another design or starting altogether a new design. The user's opinion is passed to the predicate 'MODIFY-OLD-DESIGN' where it is checked. If the user's opinion is to retain the design as it is, then it fires the rule which outputs the same result. If the opinion is to alter the design then it takes the alteration tree. For new design, it takes design detail tree causing new design. When user wishes to continue the search, then back tracking takes place in 'STORAGE-PRED3' for a next design which satisfies the condition and the same process repeats. After complete search of secondary database the rule 'SR1' fails. Then second rule with same predicate name is taken up.

```
(DEFASSERT SR2 (KNOWLEDGEBASE-SEARCH ?AA)
        < - (TELL-USER ?DN)
            (START-NEW-DESIGN ?DN))
```

As a result, design detail tree for starting new design is fired. Thus, getting into the system, searching the secondary database and firing one of the rules which affects either a new design or alteration, constitutes the main frame part.

4.3 Alteration tree

Alteration tree is taken up only when the user wishes to alter any one of the old designs, which makes predicate 'ALTERATION-PRED1' to be fired. Fig. 4.1 to 4.3 explains the alteration tree schematically. The rule is -

```
(DEFASSERT AL1 (ALTERATION-PRED1 ?WEIGHT ?DN)
        < - (NEW-VALUES-FIND1  ?WEIGHT ?DN)
            (MAJOR-CHANGES ?WEIGHT ?DN)
            (LOCAL-CHANGES ?WEIGHT ?DN)
            (SELECTION-CHANGES ?WEIGHT ?DN))
```

The alteration procedure can be broadly explained as:

- Finding from the user, whether any particular parameter needs a change, if so what is its new value. While doing so old value of that parameter is also displayed to help the user in deciding.
- Effects on design, because of the major parameter value change
- Effects on design, because of the local parameter value change
- Effect on design, when there is change in selection

The parameters that user can change in alteration tree are;

- Friction coefficient of tyre and ground
- Percentage weight acting on the auxillary wheel
- Height of centre of gravity
- Aspect ratio of the wing
- Stalling velocity of the aircraft
- Friction coefficient of braking material
- Type of undercarriage
- Type of braking system
- Height of legs at fore and aft locations

4.4 New design

A new design is taken up when there is no old design available and also when the user wishes to have new design. Fig. 4.4 to 4.9

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explains the new design tree schematically. The main frame rule which initiates the query for new design is -

```
    (DEFASSERT ND1 (START-NEW-DESIGN ?DN)
              < - (AC-WEIGHT ?WEIGHT)
                  (CHECK-WEIGHT ?WEIGHT)
                  (DETAIL-DESIG-OF ?WEIGHT))
```

The predicate 'CHECK-WEIGHT' decides the type of undercarriage, and asks user series of questions to extract values of height of center of gravity, percentage weight acting on auxillary wheel, aspect ratio, ground friction coefficient and height of leg of fore and aft location, by using 'ASK-USER' predicate. As an example for height of center of gravity location the rule can be written as -

```
(DEFASSERT TW3 (HCG-LOCATION ? WT ?D ?HCG)
    < - (ASK-USER (SOURCE ?WT ?D)
                  (TARGET ?HCG)
                  (QUESTION PLEASE GIVE THE HEIGHT OF CG LOCATION
                   IN FEET)
                  (TYPES NUMBER)))
```

The detailed design can be classified as designing of auxillary leg unit and designing of main leg unit and outputing the complete design. The rule for this is -

```
    (DEFASSERT D1 (DETAIL-DESIGN-OF ?WT)
                <-- (AC-CLASSIFICATION ?WT)
                    (AUX-LEG-UNIT ?WT)
                    (MAIN-LEG-UNIT ?WT)
                    (STORAGE-PRED 1))
```

The predicate 'AUX-LEG-UNIT' takes up detailed design of auxillary leg unit, predicate 'MAIN-LEG-UNIT' takes up detailed design of main leg unit. The parts design rule can be written as

```
(DEFASSERT DS1 (PARTS-DESIGN ?TY)
          <- (= ?TY MAIN-WHEEL)
             (AC-WEIGHT ? WEIGHT)
             (LOADS-PRED ?TY ?DY-LOAD ?ST-LOAD)
             (WHEEL-SELECTION ?TY ?DY-LOAD ?ST-LOAD))
             (LEG-DESIGN1 ?TY ?DY-LOAD ?ST-LOAD))
             (BRAKE-SELECTION ?WEIGHT))
```

and

```
(DEFASSERT DS2 (PARTS-DESIGN ?TY)
          <- (DISPLY-TB11 ?TY)
             (LOADS-PRED ?TY ?DY-LOAD ?ST-LOAD)
             (WHEEL-SELECTION ?TY ?DY-LOAD ?ST-LOAD)
             (LEG-DESIGN1 ?TY ?DY-LOAD ?ST-LOAD))
```

Rule DS1 is used for main wheel parts and rule DS2 is applic to auxiliary wheel parts design. There is no brake design for auxiliary wheel as there will not be any braking device provided in auxiliary wheel.

The Predicate 'WHEEL-SELECTION' takes up the complete wheel design. It selects the pressure, tyre and wheel-rim diameter and goes to detail design of wheel. The rule regarding detail design of wheel can be written as -

```
(DEFASSERT D13 (DETAIL-D-WHEEL ?TY)
          <- (BOLT-DESIGN ?TY)
             (GEOMETRY-CAL ?TY)
             (STRESSES-IN-WEB ?TY))
```

Here, the predicate 'BOLT-DESIGN' takes up the design of fastening bolts, predicate 'GEOMETRY-CAL' takes up the calculation of all geometrical parameters of wheel. Similarly, calculation of all stresses and checking this stresses is done through the sub-tree of predicate 'STRESSES-IN-WEB'. The rule used here is -

```
(DEFASSERT D16 (STRESSES-IN-WEB ?TY)
        <- (DISPLY-TBS1 ?TY)
           (INTENSITY-OF-PRESS1 ?TY)
           (STRESS ?TY)
           (CHECK-STRESS ?TY)
           (CHECK-SHEAR ?TY))
```

This rule is written to design the web-frame of the wheel.

The predicate 'LEG-DESIGN1' takes up a complete design of leg; rule for this is written as -

```
(DEFASSERT LG-4 (LEG-DESIGN1 ?TY ?DY-LOAD ?ST-LOAD)
        <- (LEG-DESIGN ?TY)
           (SHOCK-ABSORBER ?TY ?DY-LOAD ?ST-LOAD)
           (SHOCK-AB-TRAVEL ?TY ?DY-LOAD)
           (MAIN-VER-MEM ?TY ?DY-LOAD ?ST-LOAD)
           (ACCESSORIES ?TY ?DY-LOAD ?ST-LOAD))
```

In this rule, complete design of leg is done, which includes

- Calculating the actual leg heights, from the fore and aft heights provided by user.
- Suitable shock-absorber will be selected

- Value of shock absorber travel will be calculated
- Main vertical member will be designed
- Accessories of the leg unit will be designed

The above computations are done for both auxillary leg and main-leg units.

The rules used for main vertical member designing are -

```
(DEFASRT LG5 (MAIN-VER-MEM ?TY ?DY-LOAD ?ST-LOAD)
          <- (TYPE-OF-LANDING-LEG ?TY2)
             ( = ?TY2 RETRACTABLE)
             (ANALYS-RE ?TY ?DY-LOAD ?ST-LOAD)
             (CODE-PRED1 ?TY)
             (EXTERIOR-PENALTY-FUNCTION ?TY))
(DEFASRT LG6 (MAIN-VER-MEM ?TY ?DY-LOAD ?ST-LOAD)
          <- (LEG-HEIGHT-PRED1 ?TY ?HET)
             (> ?HET 3.0)
             (ANLYS-UNRE-BR ? TY ?DY-LOAD ?ST-LOAD)
             (CODE-PRED2 ?TY)
             (EXTERIOR-PENALTY-FUNCTION ?TY))
(DEFASRT LG7 (MAIN-VER-MEM ?TY ?DY-LOAD ?ST-LOAD)
          < - (ANLYS-UNRE-UNBR ?TY ?DY-LOAD ? ST-LOAD))
              (CODE-PRED3 ?TY)
              (EXTERIOR-PENALTY-FUNCTION ?TY))
```

Here, the predicate 'MAIN-VER-MEM' controls the type of leg design viz : Retractable, Unretractable -braced, Unretractable-unbraced. The Predicates 'ANLYS-RE', 'ANLYS-UNRE-BR' and 'ANLYS-UNRE-UNBR' takes up the analysis of respective type of legs. In this step, a sub-tree of optimization procedure, is fired through predicate 'EXTERIOR-PENALTY-FUNCTION' which performs optima weight design of main vertical leg.

The rule for optimization method is written as -

```
(DEFASRT R1 (EXTERIOR-PENALTY-FUNCTION ?TY)
          <- (INITIAL-POINT ?XI ?N)
             (DESIGN-NO ?D1)
             (AC-WEIGHT ?WT)
             (PENALTY-PARAMETER ?TY ?WT ?D1 ?R)
             (EXPONENT ?TY ?WT ?D1 ?Q)
             (CONSTANT ?TY ?WT ?D1 ?C)
             (CODE-PRED ?TY ?WW)
             (MAIN-LOOP ?N ?WW ?TY ?XI ?R
                     ?Q ?C))
```

In this step, a series of questions are asked to the user to extract values of penalty parameter, exponent and the constant. This will be done for both auxillary leg unit and main-leg-unit. The Predicate 'INITIAL-POINT', fixes the value of initial point for optimization, through the fact inserted in database. The predicate 'MAIN-LOOP' takes the control to the Devidon-Fletcher-Powell Method for unconstrained optimization and then to Cubic Interpolation Method for single variable search.

In case of main wheel the control flows to the brake design, through predicate 'BRAKE-SELECTION'. Here the kinetic energy to be absorbed by the brake is calculated using stall velocity of the aircraft. Next the friction force generated between the tyres and the ground is calculated. Then rating values for different types of brakes is calculated, and displayed to the user and his opinion is asked for. After affecting the selection, the corresponding brake system is designed.

Once all the above sub-queries becomes true, the predicate 'START-NEW-DESIGN' will also get the truth value and in turn the main query, GOAL (START), will also attain truth value and will come out of the system.

4.5 Hints to user

To activate the program the user has to type

(GOAL (START))

Now the system takes charge of knowledge base and putsforth the questions. It is useful if the user knows what are the values that he has to supply to the program before hand. The following are the list of values expected from the user alongwith some useful tips.

I. Weight of the aircraft

The value can range from 500 lb to 100,000 lb.

II. The purpose for which the aircraft will be used.

The classification list will be displayed and user is expected to respond with a code as instructed.

III. Modification tree.

Here, the user is expected to answer more than one question and the directions and instructions are displayed.

IV. Design parameter values.

- Height of centre of gravity

  There is no option for this. The designer is expected to know this value, which should be in feet.

- Weight distribution between the leg units

  This is to be mentioned as % weight acting on auxillary wheel. Usual values are, for tail wheel type 8 to 12%, for nose wheel type 10 to 15%. Default optional value taken by the program is 10%.

- Wing aspect ratio

  There is no option designer is expected to know the answer, and it should be in sq.ft.

- Friction coefficient between tyre and ground

  Usual value ranges from 0.25 to 0.8. Optional value taken by system is 0.7

- Stall velocity of the aircraft

  This is a design parameter and no option is available, which should be in mPh.

- Leg heights of fore and aft location

  There is no option designer is expected to know the answer, which should be in feet.

- Sink velocity

  This is a design parameter and no option is available, which should be in ft/sec.

V. Optimal design parameters value

- penalty parameter

  Usual value ranges from 0.01 to 1.0, option value taken by system is 1.0.

- Exponent value

  For the present problem it is found that for the value 2.0 system gives fast and good results, optional value of system is 2.0

- Constant value

  It can be anything greater than one. Optional system value is 10.0.

VI.Selection and opinions

- Type of undercarriage

  Here, he has to rate all three types according to his requirements. The values should be between 0 and 1. Optional value taken will be 0.3 for all three types.

- Brake selection

  Here the user has to just type as indicated by the program

- Design number

  User can give any design number and the design is stored under that name.

If the user fails to answer the questions where there is no option, by saying 'Don't know', the system fails to give any answer and gives an error message.

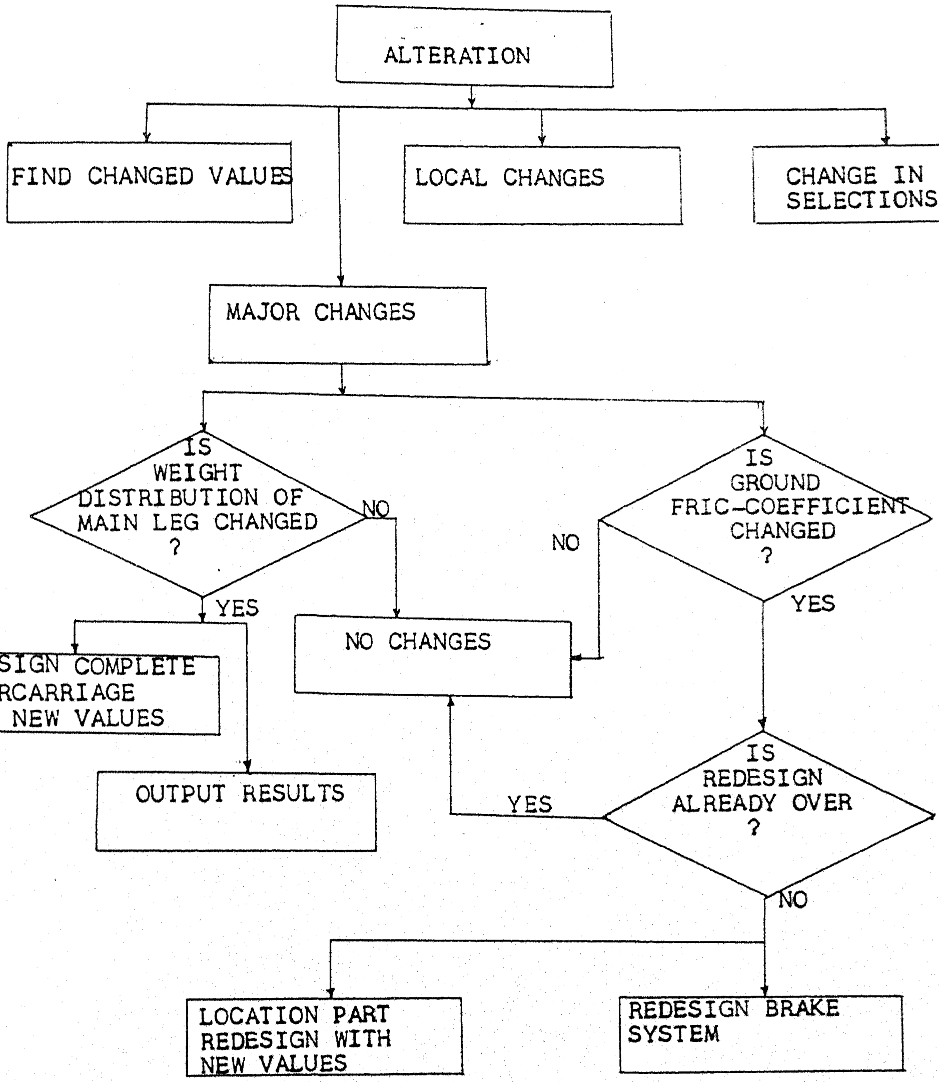
ALTERATION
FIND CHANGED VALUES
LOCAL CHANGES
CHANGE IN SELECTIONS
MAJOR CHANGES
IS WEIGHT DISTRIBUTION OF MAIN LEG CHANGED ?
NO
YES
IS GROUND FRIC-COEFFICIENT CHANGED ?
NO
YES
REDESIGN COMPLETE UNDERCARRIAGE WITH NEW VALUES
NO CHANGES
OUTPUT RESULTS
YES
IS REDESIGN ALREADY OVER ?
NO
LOCATION PART REDESIGN WITH NEW VALUES
REDESIGN BRAKE SYSTEM

Fig. 4.1 FLOW CHART FOR ALTERATION TREE-1

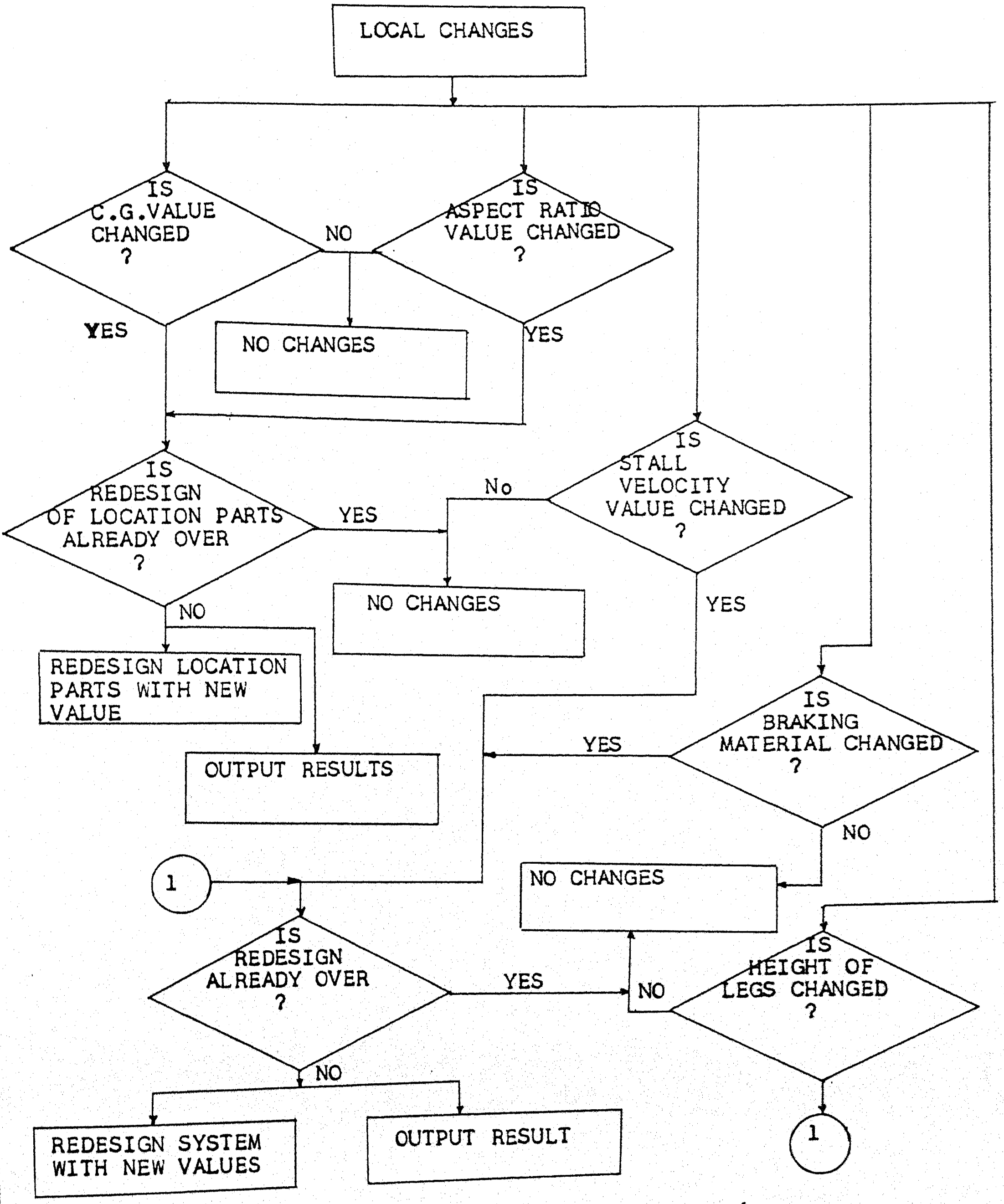
LOCAL CHANGES
IS C.G.VALUE CHANGED ?
NO
IS ASPECT RATIO VALUE CHANGED ?
YES
NO CHANGES
YES
IS REDESIGN OF LOCATION PARTS ALREADY OVER ?
YES
No
IS STALL VELOCITY VALUE CHANGED ?
NO
NO CHANGES
YES
REDESIGN LOCATION PARTS WITH NEW VALUE
IS BRAKING MATERIAL CHANGED ?
YES
OUTPUT RESULTS
NO
1
NO CHANGES
IS REDESIGN ALREADY OVER ?
YES
NO
IS HEIGHT OF LEGS CHANGED ?
NO
REDESIGN SYSTEM WITH NEW VALUES
OUTPUT RESULT
1

Fig. 4.2 : FLOW CHART FOR ALTERATION TREE-2

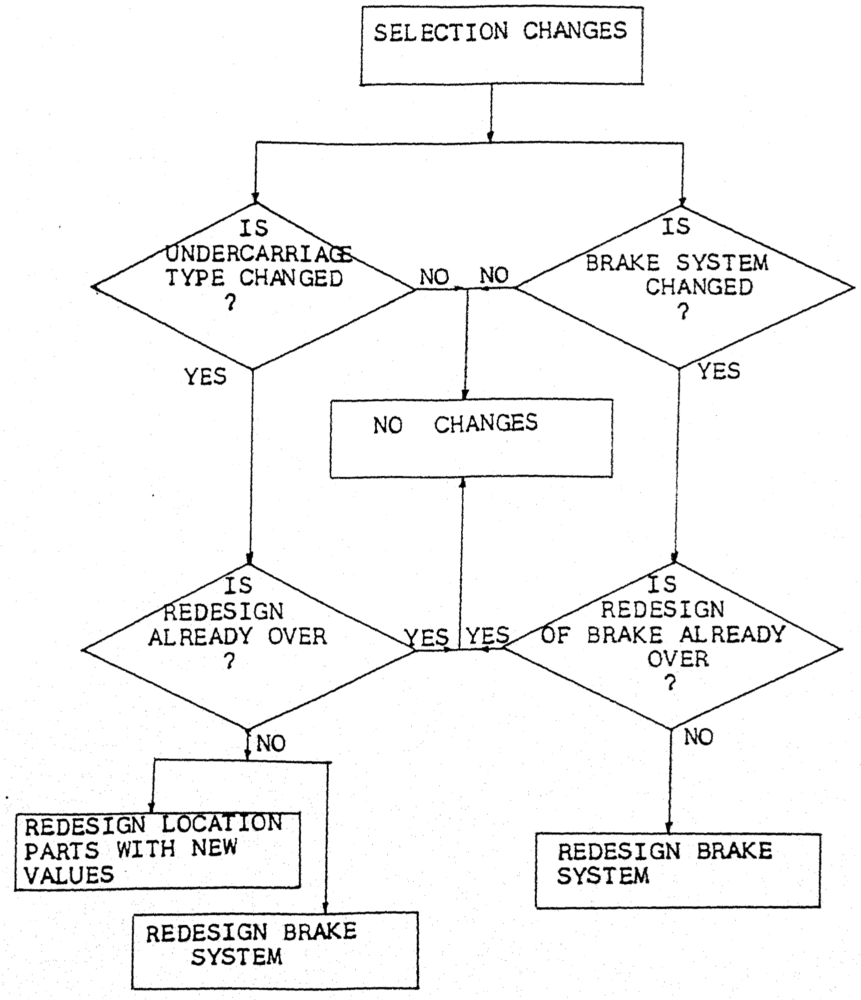
SELECTION CHANGES
IS UNDERCARRIAGE TYPE CHANGED ?
IS BRAKE SYSTEM CHANGED ?
NO
NO
YES
YES
NO CHANGES
IS REDESIGN ALREADY OVER ?
IS REDESIGN OF BRAKE ALREADY OVER ?
YES
YES
NO
NO
REDESIGN LOCATION PARTS WITH NEW VALUES
REDESIGN BRAKE SYSTEM
REDESIGN BRAKE SYSTEM

Fig. 4.3 : FLOW CHART FOR ALTERATION TREE-3.

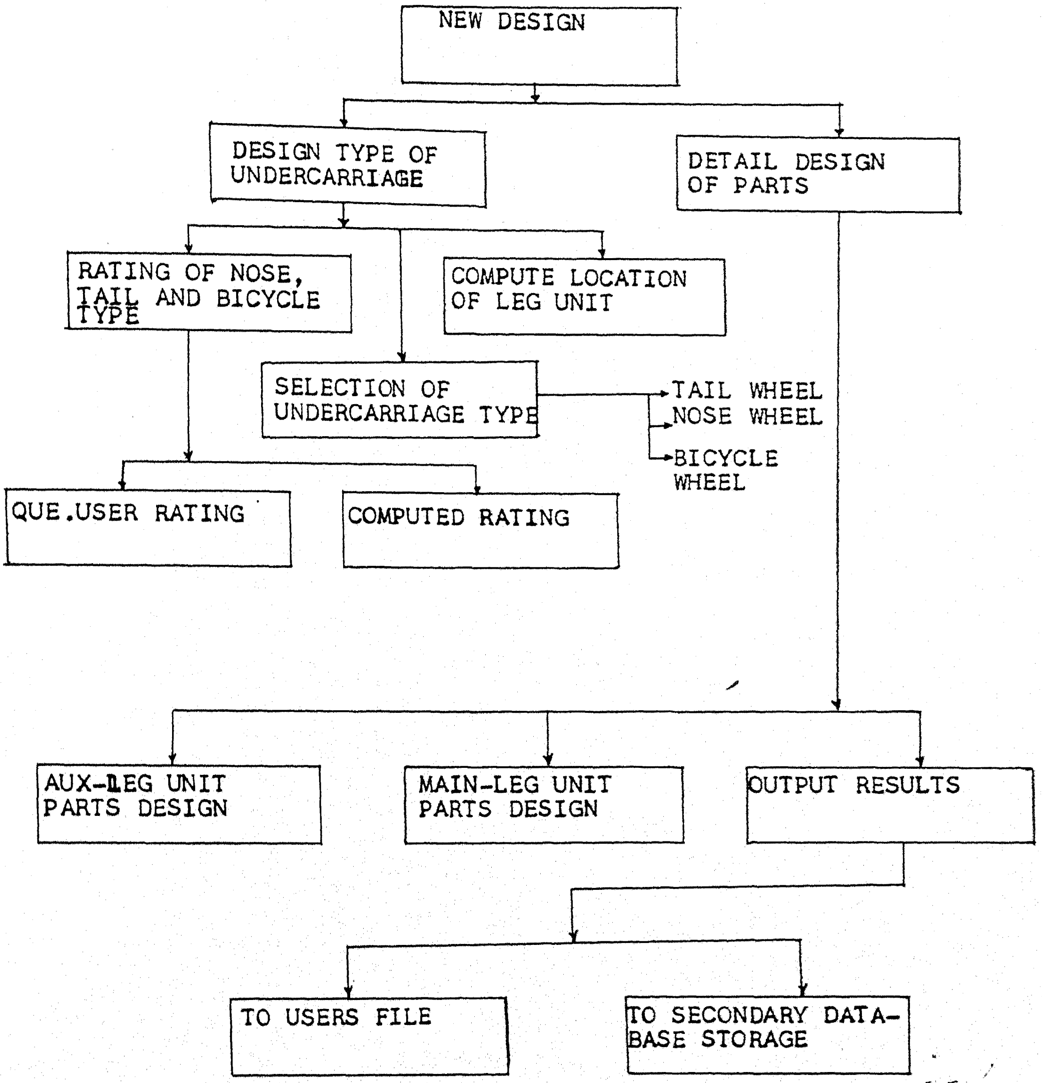
NEW DESIGN
DESIGN TYPE OF UNDERCARRIAGE
DETAIL DESIGN OF PARTS
RATING OF NOSE, TAIL AND BICYCLE TYPE
COMPUTE LOCATION OF LEG UNIT
SELECTION OF UNDERCARRIAGE TYPE
TAIL WHEEL
NOSE WHEEL
BICYCLE WHEEL
QUE.USER RATING
COMPUTED RATING
AUX-LEG UNIT PARTS DESIGN
MAIN-LEG UNIT PARTS DESIGN
OUTPUT RESULTS
TO USERS FILE
TO SECONDARY DATA-BASE STORAGE

Fig. 4.4 : FLOW CHART FOR MAIN DESIGN

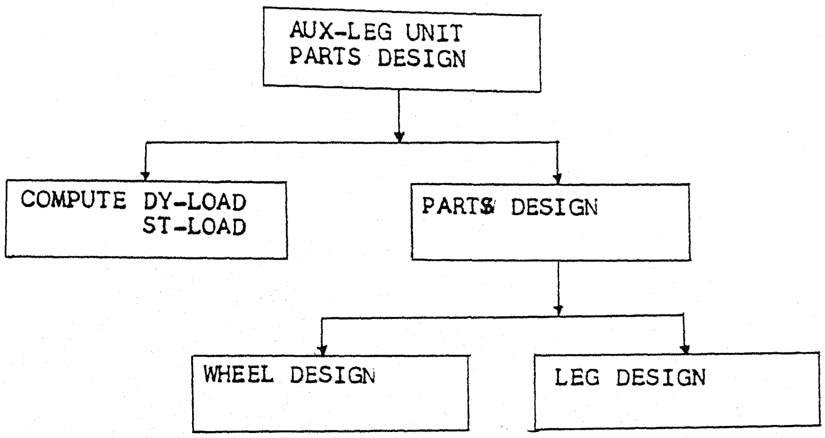

Fig. 4.5 : FLOW CHART FOR AUX-LEG UNIT DESIGN

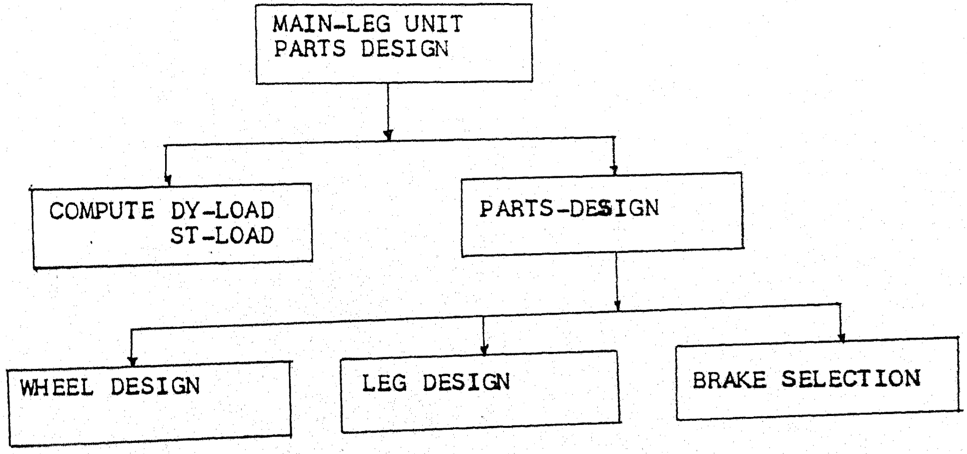

Fig. 4.6 : FLOW CHART FOR MAIN-LEG UNIT DESIGN

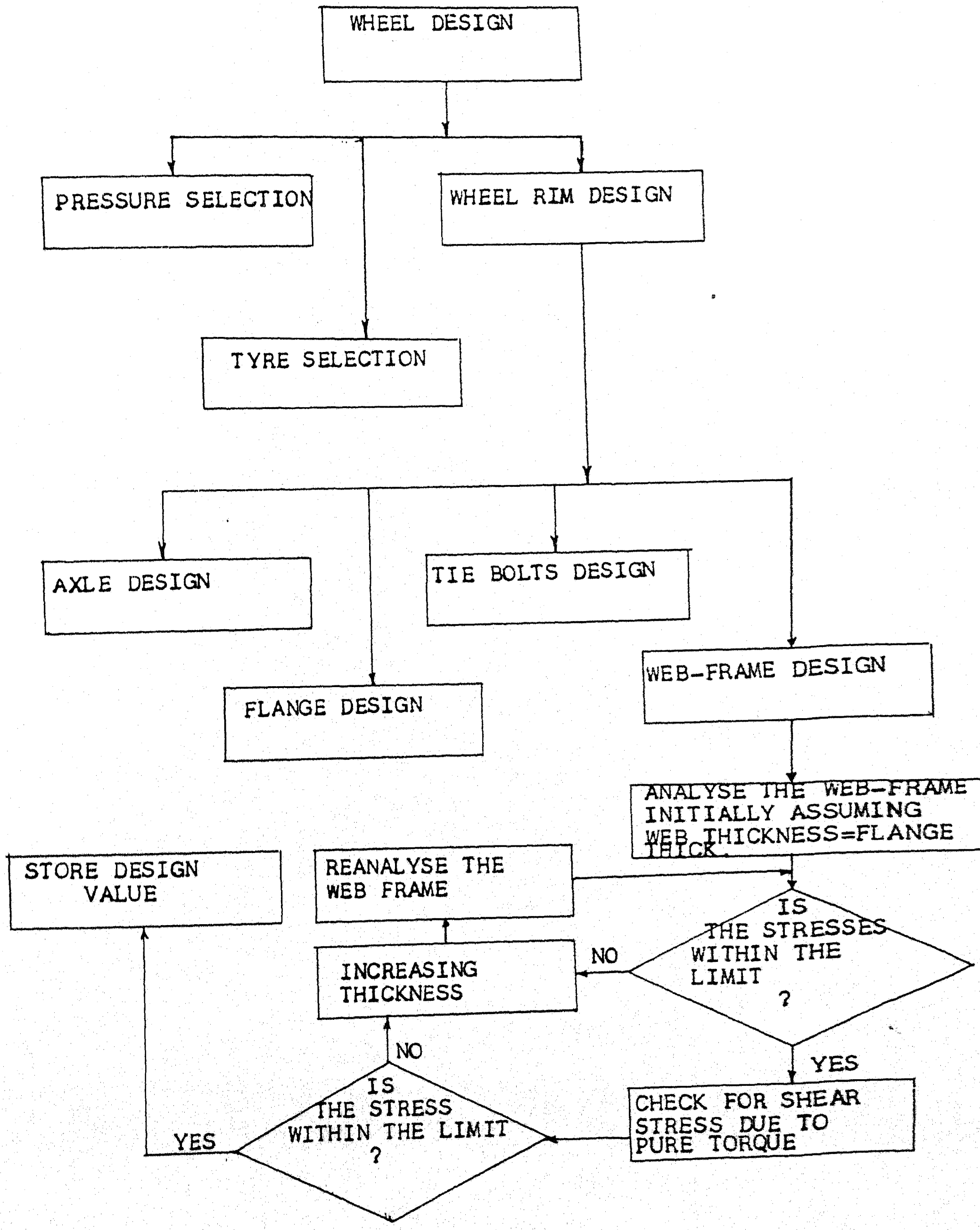

Fig. 4.7 : FLOW CHART FOR WHEEL DESIGN

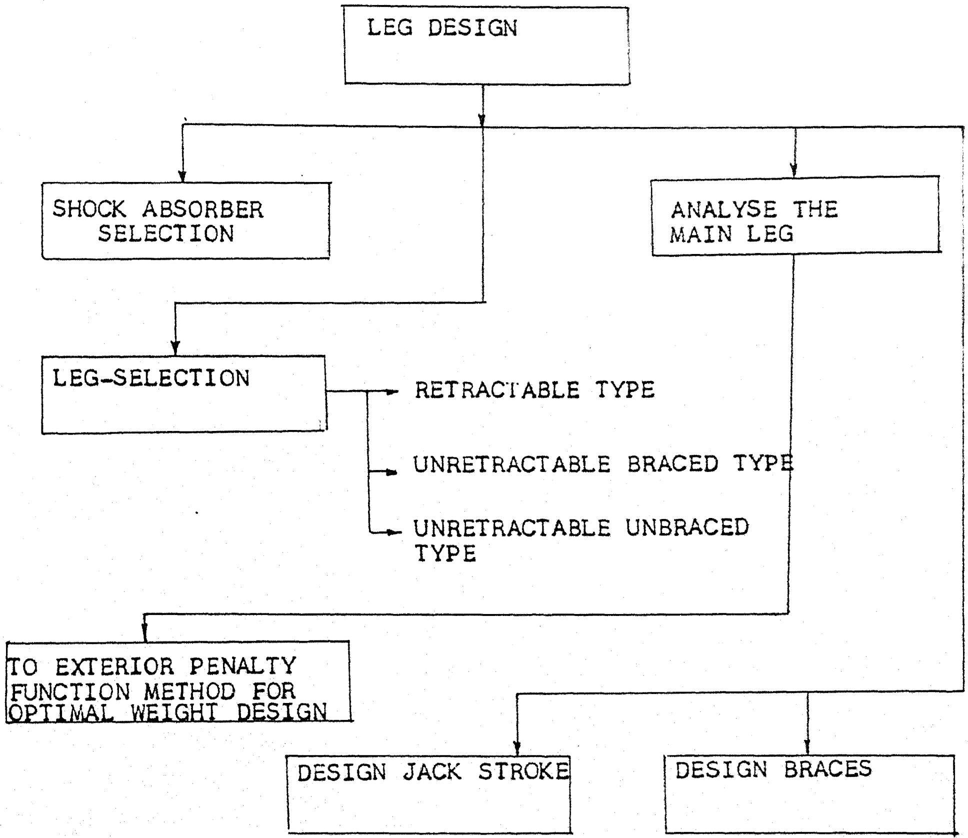

Fig. 4.8 : FLOW CHART FOR LEG DESIGN

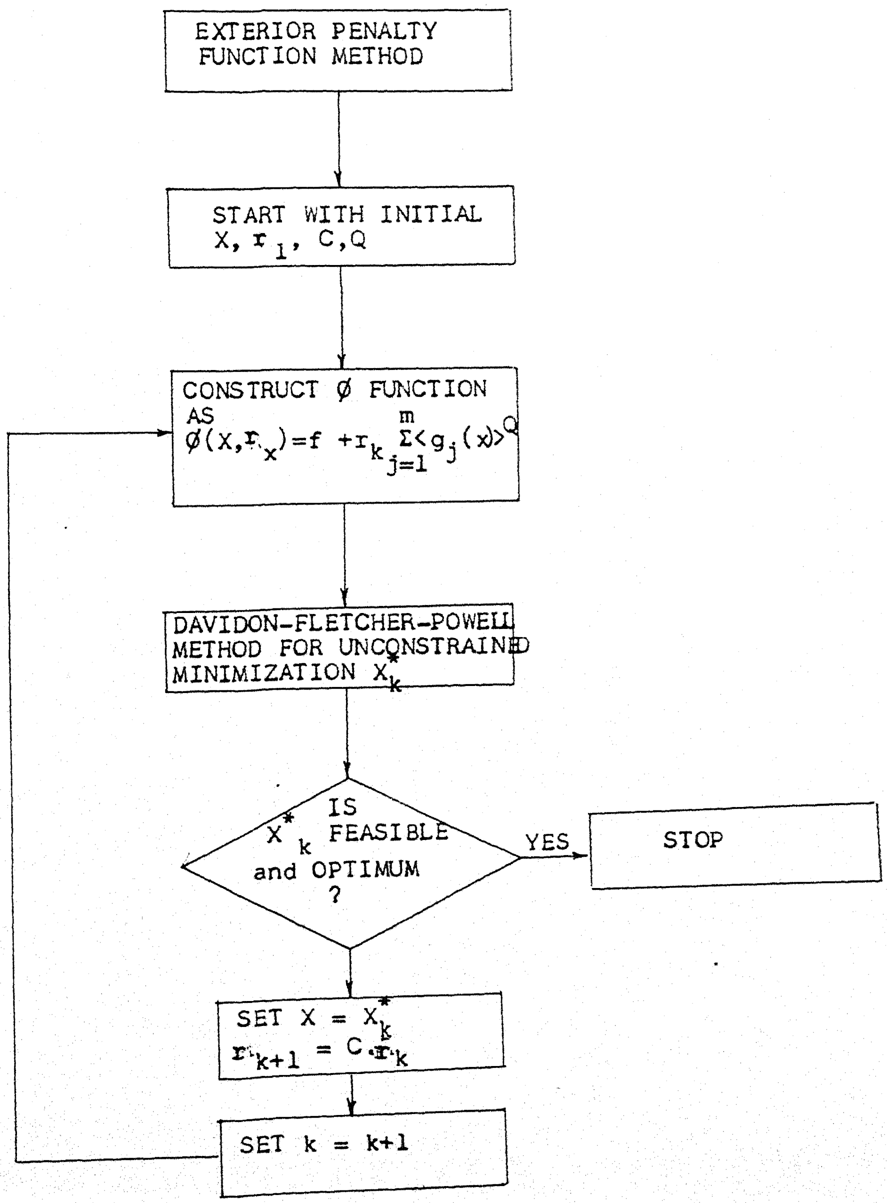
EXTERIOR PENALTY FUNCTION METHOD
START WITH INITIAL X, r_1, C,Q
CONSTRUCT Ø FUNCTION AS $\phi(X,r_x)=f+r_k\sum_{j=1}^{m}\langle g_j(x)\rangle^Q$
DAVIDON-FLETCHER-POWELL METHOD FOR UNCONSTRAINED MINIMIZATION X_k^*
IS X_k^* FEASIBLE and OPTIMUM ?
YES
STOP
SET $X = X_k^*$ $r_{k+1} = C \cdot r_k$
SET k = k+1

Fig. 4.9 : FLOW CHART FOR EXTERIOR PENALTY FUNCTION METHOD

CHAPTER 5

RESULT DISCUSSION AND CONCLUSION

5.1 Introduction

In this chapter discussions are presented on the results that are obtained by solving a few representative problems using the system. The sample problems choosen here are such that it shows all the possible usage of the system. For a proper understanding of the use and capabilities of the program developed, it is essential to run the system for solution of some general problems. This object is achieved here.

5.2 Discussion of results

The following five sample runs have been chosen to illustrate and discuss the main features and working of the program.

a. New design

This sample is selected to show the complete behaviour of the program when it solves a new problem for which there does not exist any old design. Here, the knowledge system asks the questions to user as and when the values are required. A light weight aircraft is selected, so that it is possible to have nose wheel type or tail wheel type landing gear. As the weight of aircraft supplied here is less than 10,000 lb, system designs the landing leg as unretractable type. Optimal weight design for auxillary leg is achieved in three iterations and for main leg in two iterations. The details about the questions asked, and the details of design as it has been written in output file, can be found in record file attached in Appendix.

b. Design not existing in data base

When there is change in the weight of the aircraft, compared to first sample, the system behaves in different way. The output is also different. In this sample middle class heavy aircraft of nose wheel type landing gear is solved. Here, the system solves the problem for retractable type landing leg. Optimal weight design for auxillary leg is achieved in four iterations and for main leg in three iterations. The record file is attached in Appendix.

c. Design in the data base, old design opted for

The problem is same as that of sample two. Here, the data base is searched and the user selected to retain the same old design. No design is done and the out put is copied from the data base as it is into an output file. The record file is attached in Appendix.

d. A design existing in data base, new design option

The weight of the aircraft and its purpose is same as that of example two and three. The system responds with displaying old design details, as the design has been already done. Here, the response given by the user is to start a new design. The system designs the complete undercarriage. Behaviour of the system is same as for sample two, only change is, less number of questions is asked. The design details are similar to sample two. Thus, it proves the system is consistant for consistant responee from user. Record file attached in Appendix.

e. Design in data base - Alteration option

For comparison purposes the same as earlier example input, weight and purpose of the aircraft are given in this sample too. After searching the data base the user has responded to alter one of the designs. In this case the system respond with new set of questions, as can be found in record file. The user likes to change the % weight that auxillary wheel takes and stalling velocity. Since former one is a major change, it can be noticed that, complete undercarriage has been redesigned. The difference in the designed values can be noticed from the record file attached in Appendix.

It can be noted from record file that, in first sample run, design of landing gear is done for tail wheel type. An optimal weight design is performed for unretractable unbraced type landing leg layout. Internal diameter for auxillary leg is 0.363 inches and external diameter is 0.595 inches. And internal diameter for main leg is 1.004 inches and external diameter is 1.634 inches. In second sample run, the weight and purpose of aircraft is different than first. Here, the design of landing gear is done for nose wheel type. An optimal weight design is performed for retractable, landing leg layout. Internal diameter from auxillary leg is 0.6996 inches and external diameter is 1.131 inches. And internal diameter for main leg is 1.762 inches and external diameter is 2.889 inches, which clearly indicates that system behaves differently for different problems.

5.3 Conclusion

The knowledge system for landing gear design with optimised leg has been developed. The system has high degree of flexibility, and gains 'experience' in each run. It gives suggestions and aids user in taking decision or answering the questions asked. If the user has difficulty in deciding, he can ask the system to take decisions. In that case it takes reasonable decision and informs the user. It explains the design procedure. It may be used as a teaching aid for the beginner and effective tool for an experienced designer. It can also be used as sub-system by attaching to another main system.

The design procedure details of the landing gear has been worked out for some components of the landing gear. These include tyre design, complete wheel design, optimal weight design of landing leg, retraction details and brake design. The selection made in the process include type of landing gear, type of landing leg (retraction method and mechanism), tyre pressure, shock absorber, and brake system type.

After running this knowledge system for large number of times, it should be possible to get a detail design for any type of problem without designing the landing gear completely, that is just by modifying some part of the landing gear design.

5.4 Suggestions for further development

To make design more complete, the design details of other mechanism in the landing gear like shock absorber fixing arrangement, the detail of mechanical part of shock absorber, other types of retraction method and mechanism etc. can be coded into the databa Thus making design more complete. Also advanced designs, if and when available for the parts of landing gear that has been already coded, can be added to the knowledge base from time to time.

The weight optimization for other important members of undercarriage can be incorporated to generate more economical solution.

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APPENDIX

SAMPLE RUN-1

```
RECORD FILE DSK: SS1 OPENED 05-FEB-88 21:28:40
NIL
<9>(GOAL (START))


               ************************************
               Welcome to the UNDERCARRIGE DESIGNER
               ************************************


          ------------------------------------------------------------
          I will now proceed to ask you series of questions pertaining
          to the design which you want to perform. If you donot
          understand the question type  WHAT  for the explanation of the
          question.
          ------------------------------------------------------------

TYPE  CON  FOR CONTINUE>CON

(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >5700

=====================================================
1 AGRICULTURAL PURPOSE                     TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER           TYPE A2
3 TRAINER 1 2 SEATER                       TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER           TYPE A4
5 UTILITY AIRCRAFT                         TYPE A5
6 LIGHT,AMETURE A/C                        TYPE A6
7 FIGHTERS                                 TYPE A7
8 PASSENGER,AIRSERVICE                     TYPE A8
9 CARGO TRANSPORT                          TYPE A9
10 SPORTS PLANES                           TYPE A10
==========================================================

(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A1

(QUESTION NO DESIGN HAS BEEN DONE UNDER THIS CATEGORY AND WEIGHT RANGE SO NEW
DESIGN WILL BE DONE PLEASE TYPE A DESIGN NUMBER LIKE DES1 OR SO) >DS1

***************************************************
DESIGN WILL BE DONE FOR UNRETRACTABLE LANDING GEAR
***************************************************

(QUESTION PLEASE GIVE YOUR RATING VALUES FOR NOSE TAIL AND BICYCLE WHEEL TYPE
IN THE RANGE OF 0 TO 1) >0.3 0.6 0.2

================================================================
          LANDINGGEAR                          TOTAL
             TYPE                            RATING
          NOSEWHEEL                            9.6618535

          TAILWHEEL                            39.754386

          BICYCLE                            0.40000000E-3
========================================================


DESIGN  WILL BE DONE FOR TAILWHEEL-TYPE
(QUESTION PLEASE GIVE THE VALUE OF THE GROUND FRICTION COEFFICIENT WITHIN THE
RANGE 0.25 TO 0.79999999) >0.55

(QUESTION PLEASE GIVE THE HEIGHT OF CG LOCATION IN FEET) >6.50

(QUESTION PLEASE GIVE WHAT PERCENT OF TOTAL WEIGHT WOULD YOU LIKE THE AUXILLAR
Y WHEEL TO TAKE) >9.0

-----------------------------------------------

     UNDERCARRIAGE LOCATION DETAILS

FORE LOCATION              1.9444444  feet

AFT LOCATION               5.1999999  feet

WHEEL BASE                 7.1444444  feet

WHEEL TRACK                27.584699  feet

------------------------------------------------
```

```
LIGHT-CLASS-AC

(QUESTION FOR ABOVE CALCULATED FORE AND AFT LOCATIONS WHAT WILL BE THE DISTANC
E BETWEEN GROUND AND SURFACE OF AIRCRAFT BODY WHERE LANDING LEG IS TO BE ASSEMB
LED WHEN TYRES AND SHOCK ABSORBERS ARE FULLY SQUASHED IN FEET) >2.5 2.0

********************
PARTS DESIGN
********************


               DESIGN OF AUX-WHEEL
               ======================
AUX-WHEEL PRESSURE WILL BE CALCULATED

AUX-WHEEL TYRE SELECTION
          NUMBER OF TYRES IN AUX-WHEEL 1.0

STATIC LOAD ON AUX-WHEEL 2000.0

PRESSURE FINAL =  40.0

AUX-WHEEL  DETAILS
                  DIAMETER OF TYRE        22.599997
                  TYRE WIDTH               6.0
                   WHEEL RIM DIAMETER     12.0

               ----------------------------------
               DETAILED DESIGN OF AUX-WHEEL PARTS
               ----------------------------------
WHEEL WILL BE DESIGNED AS MODERN SPLIT TYPE WHEEL

FINDING AXLE DIA

SOLID AXLE DIA  0.88520335

FLANGE THICKNESS = 0.91622552E-1

DESIGNING FASTENING BOLTS
MATERIAL USED OPEN-HEARTH NICKEL STEEL

NUMBER OF BOLTS 8.0
DIA OF BOLT 0.26973892
               FINDING MAXIMUM STRESSES IN WEB OF AUX-WHEEL
               --------------------------------------------
ASSUMING THICKNESS OF WEB EQUALS TO THICKNESS OF FLANGE

(QUESTION PLEASE SPECIFY STALLING VELOCITY IN MPH) >45.0

          STRESSES CALCULATED AS
                         MAXIMUM RADIAL STRESS -14544.625
                         MAXIMUM TANGENTIAL STRESS 27298.942
                         MAXIMUM SHEAR STRESS 798.69154

---------------------------------------------------
STRESSES CALCULATED ARE GREATER THAN SAFE STRESSES
REDESIGNING WEB THICKNESS
---------------------------------------------------

REDESIGNED THICKNESS OF WEB OF AUX-WHEEL 0.10421661

CHECKING ABOVE DESIGNED THICKNESS FOR A TORQUE

MAXIMUM SHEAR STRESS DUE TO PURE TORQUE 2123.2534

ABOVE CALCULATED SHEAR STRESS IS WITH IN THE LIMITS
FINAL WEB THICKNESS  0.10421661 inch
               DESIGN OF AUX-WHEEL LEG
               ======================

HEIGHT OF AUX-WHEEL LEG 2.0

 STEEL  SPRING TYPE OF SHOCK-ABSORBER
(QUESTION WHAT IS THE MAXIMUM LIMIT FOR SINK VELOCITY IN FT PER SEC) >12.0


SHOCK ABSORBER TRAVEL 1.2783240 FT

ANALYSING THE LANDING LEG
```

```
OPTIMAL WEIGHT DESIGN OF MAIN VERTICAL MEMBER STARTS
----------------------------------------------------
(QUESTION WHAT IS VALUE OF PENALTY PARAMETER) >1.0

(QUESTION WHAT IS VALUE OF EXPONENT) >2.0

(QUESTION WHAT IS VALUE OF CONSTANT) >10.0
DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 0.30860192
          INTERNAL DIAMETER 0.18450074

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 0.42561022
          INTERNAL DIAMETER 0.26856005

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 0.59488715
          INTERNAL DIAMETER 0.36288116

=====================================================

DESIGNED DIMENSIONS OF MAIN VERTICAL MAMBER IN inch
                         EXTERNAL DIAMETER  0.59488715
                         INTERNAL DIAMETER  0.36288116
=====================================================


NO ASCESSORIES TO THE LANDING LEG ONLY A VERTICAL STRUT

               DESIGN OF MAIN-WHEEL
               =======================

MAIN-WHEEL PRESSURE WILL BE CALCULATED

MAIN-WHEEL TYRE SELECTION
          NUMBER OF TYRES IN MAIN-WHEEL 2.0

STATIC LOAD ON MAIN-WHEEL 2593.5

PRESSURE FINAL =  59.783333

MAIN-WHEEL  DETAILS
                  DIAMETER OF TYRE          22.599997
                  TYRE WIDTH                 6.0
                   WHEEL RIM DIAMETER       12.0

               ----------------------------------
               DETAILED DESIGN OF MAIN-WHEEL PARTS
               ----------------------------------
WHEEL WILL BE DESIGNED AS MODERN SPLIT TYPE WHEEL

FINDING AXLE DIA

HOLLOW AXLE OF OUTER DIA  1.7431800
FLANGE THICKNESS = 0.87287721E-1

DESIGNING FASTENING BOLTS
MATERIAL USED OPEN-HEARTH NICKEL STEEL

NUMBER OF BOLTS 12.0
DIA OF BOLT 0.21496777
               FINDING MAXIMUM STRESSES IN WEB OF MAIN-WHEEL
               ---------------------------------------------
ASSUMING THICKNESS OF WEB EQUALS TO THICKNESS OF FLANGE

          STRESSES CALCULATED AS
                         MAXIMUM RADIAL STRESS -11587.045
                         MAXIMUM TANGENTIAL STRESS 23449.328
                         MAXIMUM SHEAR STRESS 4332.2966

--------------------------------------------------
STRESSES CALCULATED ARE WITH IN THE LIMITS
THICKNESS OF WEB OF MAIN-WHEEL 0.87287721E-1
--------------------------------------------------

CHECKING ABOVE DESIGNED THICKNESS FOR A TORQUE

MAXIMUM SHEAR STRESS DUE TO PURE TORQUE 13016.233

ABOVE CALCULATED SHEAR STRESS IS WITH IN THE LIMITS
FINAL WEB THICKNESS  0.87287721E-1 inch
```

```
                    DESIGN OF MAIN-WHEEL LEG
                    ========================

HEIGHT OF MAIN-WHEEL LEG 2.5
PLEASE GIVE YOUR WEIGHTAGE FOR THE FOLLOWING
SPRING CHARACTORS IN THE RANGE OF 1 TO 10 , 10 BEING MAXIMUM
  1   SIMPLICITY OF SHOCK ABSORBER
  2   WEIGTH OF SHOCK-ABSORBER
  3   EFFICIENCY OF ABSORBER
  4   RELIABILITY OF ABSORBER
(QUESTION TYPE YOUR ANSWERS WITH A BLANK SEPERATING THEM) >6 5 9 7
FOR MAIN WHEEL OLEO-PNUEMATIC SHOCK ABSORBER IS  USED

SHOCK ABSORBER TRAVEL 0.69474133 FT

ANALYSING THE LANDING LEG


OPTIMAL WEIGHT DESIGN OF MAIN VERTICAL MEMBER STARTS
----------------------------------------------------

(QUESTION WHAT IS VALUE OF PENALTY PARAMETER) >1.0

(QUESTION WHAT IS VALUE OF EXPONENT) >2.0

(QUESTION WHAT IS VALUE OF CONSTANT) >10.0

DESIGNED DIMENSIONS
           EXTERNAL DIAMETER 1.0150157
           INTERNAL DIAMETER 0.64127270

DESIGNED DIMENSIONS
           EXTERNAL DIAMETER 1.6736965
           INTERNAL DIAMETER 1.0042179

=====================================================

DESIGNED DIMENSIONS OF MAIN VERTICAL MAMBER IN inch
                         EXTERNAL DIAMETER  1.6736965
                         INTERNAL DIAMETER  1.0042179
=====================================================


NO ASCESSORIES TO THE LANDING LEG ONLY A VERTICAL STRUT

                DESIGN OF BRAKES
                ================

KINETIC ENERGY THAT HAS TO BE ABSORBED BY BRAKES IS 96956.999

                FINDING FORCE REQUIRED TO BRAKE STOP THE VEHICLE AFTER LANDING

..................................
SYSTEM RATING FOR BRAKE TYPES
..............................

----------------------------------------------------------------------------
    BRAKE TYPE                  SYS.RATING VALUE                SHORT FORM
----------------------------------------------------------------------------

   FOR THE SYSTEM TO CONTINUE ITS OWN DESIGN                   CON

   SHOE BRAKE                    4.9999995                         SHOE

   DRUM BRAKE                    3.9999995                         DRUM

   DISC BRAKE                    30.0                              DISC

   NO BRAKING                    2.9999997                         NO-BR

   PARACHUTE BRAKE               0.99999990E-1                     PARA
----------------------------------------------------------------------------

(QUESTION PLEASE TYPE YOUR OPINION FOR BRAKE SELECTION) >DISC

NO OF FRICTION SURFACES IS    1
NO OF FRICTION PLATES    1


YES
Should I try for another answer (Y/N):>N

OK
<10>RECORDFILE

RECORD FILE DSK: sS1 CLOSED 05-FEB-88 21:34:31
```

```
================================================================
          DESIGN DETAIL OF UNDER CARRIAGE
================================================================
          DESIGN NUMBER -----------  DS1
----------------------------------------------------------------
           PURPOSE OF THE AIRCRAFT -----  A1
----------------------------------------------------------------
          WEIGHT OF THE A/C -----  5700
          TYPE OF LANDING GEAR ----  PT
          TYPE OF LANDING LEG ----- UNRETRACTABLE  TYPE
----------------------------------------------------------------
          LOCATION DETAILS
----------------------------------------------------------------
          WHEEL BASE ------  7.1444444 feet
          WHEEL TRACK -----  27.584699 feet
================================================================
           AUXILIARY LEG UNIT DETAILS ......
================================================================
           AUXILIARY WHEEL DETAILS.......
----------------------------------------------------------------
           AUX-WHEEL PRESSURE --- 40.0  psi
           TYRE DIAMETER  ---- 22.599997    inches
           TYRE WIDTH ----     6.0   inches
           RIM DIAMETER -----  12.0   inches
           AXLE DIAMETER ---- 0.88520335   inches
           NUMBER OF BOLTS ------ 8
           DIAMETER OF BOLT ______ 0.26973892   inches
           WEB THICKNESS ----- 0.10421661  inches
----------------------------------------------------------------
           AUXILIARY WHEEL LEG DETAILS.........
----------------------------------------------------------------
           SHOCK ABSORBER ---- STEEL-SPRING
           HEIGHT OF LEG -----  2.0feet
           EXTERNAL DIAMETER ---- 0.59488715  inches
           INTERNAL DIAMETER ----0.36288116  inches
           ASCESSORIES DETAILS -----
           BRACE ONE ---
                     LENGTH ---- NIL  inches
                     EXTERNAL DIAMETER ----NIL  inches
                     INTERNAL DIAMETER ----NIL  inches
           BRACE TWO ----
                     LENGTH ----  NIL  inches
                     EXTERNAL DIAMETER ----  NIL  inches
                     INTERNAL DIAMETER ----  NIL  inches
           JACK STROKE ----  NILfeet
           RIM FLANGE THICKNESS -- 0.91622552E-1   inches
================================================================
               MAIN LEG UNIT DETAILS .....
================================================================
           MAIN WHEEL DETAILS......
----------------------------------------------------------------
           MAIN WHEEL PRESSURE ----  59.783333  psi
           TYRE DIAMETER ----  22.599997   inches
           TYRE WIDTH ----  6.0    inches
           RIM DIA OF THE MAIN WHEEL ----  12.0   inches
           AXLE DIA OF THE MAIN WHEEL ----  1.7431800   inches
           NUMBER OF BOLTS -----  12
           DIAMETER OF BOLT ----  0.21496777  inches
           WEB THICKNESS ----  0.87287721E-1  inches
----------------------------------------------------------------
          MAIN WHEEL LEG DETAILS ------
----------------------------------------------------------------
           SHOCK ABSORBER ----  OLEO-PNUEMATIC
           HEIGHT OF LEG ----2.5feet
           EXTERNAL DIAMETER ----  1.6736965  inches
           INTERNAL DIAMETER ----  1.0042179  inches
           ASCESSORIES DETAILS ----
           BRACE ONE ----
                     LENGTH ----  NIL  inches
                     EXTERNAL DIAMETER ----  NIL  inches
                     INTERNAL DIAMETER ----  NIL  inches
           BRACE TWO ----
                     LENGTH ----  NIL  inches
                     EXTERNAL DIAMETER ----  NIL  inches
                     INTERNAL DIAMETER ----  NIL  inches
           JACK STROKE ----  NIL  inches
           FLANGE THICKNESS OF THE RIM ----0.87287721E-1    inches
----------------------------------------------------------------
           TYPE OF THE BRAKEING SYSTEM ---  DISC ---
 ===============================================================
                     ......END OF DETAILS .....
================================================================

NIL
```

SAMPLE RUN-2

```
RECORD FILE DSK: SS1 OPENED 05-FEB-88 21:43:02
NIL
<9>(GOAL (START))


               *************************************
               Welcome to the UNDERCARRIGE DESIGNER
               *************************************


          -------------------------------------------------------------
          I will now proceed to ask you series of questions pertaining
          to the design which you want to perform. If you donot
          understand the question type  WHAT  for the explanation of the
          question.
          -------------------------------------------------------------

TYPE  CON  FOR CONTINUE>CON

(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >16500

========================================================
1 AGRICULTURAL PURPOSE                      TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER            TYPE A2
3 TRAINER 1 2 SEATER                        TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER            TYPE A4
5 UTILITY AIRCRAFT                          TYPE A5
6 LIGHT,AMETURE A/C                         TYPE A6
7 FIGHTERS                                  TYPE A7
8 PASSENGER,AIRSERVICE                      TYPE A8
9 CARGO TRANSPORT                           TYPE A9
10 SPORTS PLANES                            TYPE A10
===========================================================

(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A4

(QUESTION NO DESIGN HAS BEEN DONE UNDER THIS CATEGORY AND WEIGHT RANGE SO NEW
DESIGN WILL BE DONE PLEASE TYPE A DESIGN NUMBER LIKE DES1 OR SO) >DS2


**************************************************
DESIGN WILL BE DONE FOR RETRACTABLE LANDING GEAR
**************************************************

 ..............................................

DESIGN WILL BE DONE FOR NOSEWHEEL-TYPE
........................................

(QUESTION PLEASE GIVE THE HEIGHT OF CG LOCATION IN FEET) >7.9

(QUESTION PLEASE GIVE WHAT PERCENT OF TOTAL WEIGHT WOULD YOU LIKE THE AUXILLAR
Y WHEEL TO TAKE) >12.0

(QUESTION PLEASE SPECIFY THE ASPECT-RATIO OF THE PLANE) >7.0

-----------------------------------------------

     UNDERCARRIAGE LOCATION DETAILS

FORE LOCATION                11.236668   feet

AFT LOCATION                 1.5322729   feet

WHEEL BASE                   12.768941   feet

WHEEL TRACK                  10.368749   feet

------------------------------------------------

MEDIUM CLASS AC

(QUESTION FOR ABOVE CALCULATED FORE AND AFT LOCATIONS WHAT WILL BE THE DISTANC
E BETWEEN GROUND AND SURFACE OF AIRCRAFT BODY WHERE LANDING LEG IS TO BE ASSEMB
LED WHEN TYRES AND SHOCK ABSORBERS ARE FULLY SQUASHED IN FEET) >4.0 4.5

********************
PARTS DESIGN
********************
```

```
                DESIGN OF AUX-WHEEL
                ======================

AUX-WHEEL PRESSURE WILL BE CALCULATED

AUX-WHEEL TYRE SELECTION
          NUMBER OF TYRES IN AUX-WHEEL 1.0

STATIC LOAD ON AUX-WHEEL 3000.0

PRESSURE FINAL =  101.66666

AUX-WHEEL  DETAILS

                   DIAMETER OF TYRE          18.0
                   TYRE WIDTH                 5.6200000
                    WHEEL RIM DIAMETER       8.0

                ----------------------------------
                DETAILED DESIGN OF AUX-WHEEL PARTS
                ---------------------------------
WHEEL WILL BE DESIGNED AS MODERN SPLIT TYPE WHEEL

FINDING AXLE DIA
HOLLOW AXLE OF OUTER DIA  1.3329111

FLANGE THICKNESS = 0.22893568

DESIGNING FASTENING BOLTS
MATERIAL USED OPEN-HEARTH NICKEL STEEL
NUMBER OF BOLTS 8.0
DIA OF BOLT 0.34813969

                FINDING MAXIMUM STRESSES IN WEB OF AUX-WHEEL
                --------------------------------------------
ASSUMING THICKNESS OF WEB EQUALS TO THICKNESS OF FLANGE

(QUESTION PLEASE SPECIFY STALLING VELOCITY IN MPH) >50.0

           STRESSES CALCULATED AS
                          MAXIMUM RADIAL STRESS -6135.4393
                          MAXIMUM TANGENTIAL STRESS 17204.034
                          MAXIMUM SHEAR STRESS 777.04625

----------------------------------------------------
STRESSES CALCULATED ARE WITH IN THE LIMITS
THICKNESS OF WEB OF AUX-WHEEL 0.22893568
----------------------------------------------------

CHECKING ABOVE DESIGNED THICKNESS FOR A TORQUE

MAXIMUM SHEAR STRESS DUE TO PURE TORQUE 2064.5896

ABOVE CALCULATED SHEAR STRESS IS WITH IN THE LIMITS
FINAL WEB THICKNESS  0.22893568 inch
                DESIGN OF AUX-WHEEL LEG
                =======================

HEIGHT OF AUX-WHEEL LEG 4.1666666

PNUEMATIC TYPE OF SHOCK ABSORBER
(QUESTION WHAT IS THE MAXIMUM LIMIT FOR SINK VELOCITY IN FT PER SEC) >12.0


SHOCK ABSORBER TRAVEL 0.79895253 FT

ANALYSING THE LANDING LEG


OPTIMAL WEIGHT DESIGN OF MAIN VERTICAL MEMBER STARTS
----------------------------------------------------

(QUESTION WHAT IS VALUE OF PENALTY PARAMETER) >1.0

(QUESTION WHAT IS VALUE OF EXPONENT) >2..0

Number of answers provided  does not match number needed.
Please type 1 answer(s) separated by spaces
(QUESTION WHAT IS VALUE OF EXPONENT) >2.0

(QUESTION WHAT IS VALUE OF CONSTANT) >10.0
```

```
DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 0.59853744
          INTERNAL DIAMETER 0.41170996

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 0.66103731
          INTERNAL DIAMETER 0.41768303

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 0.78270285
          INTERNAL DIAMETER 0.46179468

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 1.1313690
          INTERNAL DIAMETER 0.69960466
====================================================
DESIGNED DIMENSIONS OF MAIN VERTICAL MAMBER IN inch
                         EXTERNAL DIAMETER  1.1313690
                         INTERNAL DIAMETER  0.69960466
====================================================


DESIGNING ASCESSORIES OF LANDING LEG
====================================

               DESIGNED DIMENSIONS OF CE
                         INTERNAL DIAMETER 0.45424827
                         EXTERNAL DIAMETER 0.90849655
               DESIGNED DIMENSIONS OF ED
                         INTERNAL DIAMETER 0.86259940
                         EXTERNAL DIAMETER 1.2932524


DESIGNED JACK-STROKE 2.2674881 FEET
               DESIGN OF MAIN-WHEEL
               ======================

MAIN-WHEEL PRESSURE WILL BE CALCULATED

MAIN-WHEEL TYRE SELECTION
          NUMBER OF TYRES IN MAIN-WHEEL 2.0

STATIC LOAD ON MAIN-WHEEL 7260.0

PRESSURE FINAL =  74.842104

MAIN-WHEEL  DETAILS
                  DIAMETER OF TYRE           32.199995
                  TYRE WIDTH                  9.1000000
                   WHEEL RIM DIAMETER        15.5

               ---------------------------------
               DETAILED DESIGN OF MAIN-WHEEL PARTS
               ---------------------------------
WHEEL WILL BE DESIGNED AS MODERN SPLIT TYPE WHEEL

FINDING AXLE DIA

HOLLOW AXLE OF OUTER DIA  2.6550889
FLANGE THICKNESS = 0.16928348

DESIGNING FASTENING BOLTS
MATERIAL USED OPEN-HEARTH NICKEL STEEL

NUMBER OF BOLTS 12.0
DIA OF BOLT 0.34023525
               FINDING MAXIMUM STRESSES IN WEB OF MAIN-WHEEL
               ---------------------------------------------
ASSUMING THICKNESS OF WEB EQUALS TO THICKNESS OF FLANGE

          STRESSES CALCULATED AS
                         MAXIMUM RADIAL STRESS -9620.1287
                         MAXIMUM TANGENTIAL STRESS 21851.161
                         MAXIMUM SHEAR STRESS 3537.1483

----------------------------------------------------
STRESSES CALCULATED ARE WITH IN THE LIMITS
THICKNESS OF WEB OF MAIN-WHEEL 0.16928348
----------------------------------------------------
```

```
CHECKING ABOVE DESIGNED THICKNESS FOR A TORQUE

MAXIMUM SHEAR STRESS DUE TO PURE TORQUE 10279.126

ABOVE CALCULATED SHEAR STRESS IS WITH IN THE LIMITS
FINAL WEB THICKNESS  0.16928348 inch

               DESIGN OF MAIN-WHEEL LEG
               ========================

HEIGHT OF MAIN-WHEEL LEG 4.3541666

PLEASE GIVE YOUR WEIGHTAGE FOR THE FOLLOWING
SPRING CHARACTORS IN THE RANGE OF 1 TO 10 , 10 BEING MAXIMUM

  1  SIMPLICITY OF SHOCK ABSORBER
  2  WEIGTH OF SHOCK-ABSORBER
  3  EFFICIENCY OF ABSORBER
  4  RELIABILITY OF ABSORBER
(QUESTION TYPE YOUR ANSWERS WITH A BLANK SEPERATING THEM) >5 8 5 8

FOR MAIN WHEEL OLEO-PNUEMATIC SHOCK ABSORBER IS  USED

SHOCK ABSORBER TRAVEL 0.69474133 FT

ANALYSING THE LANDING LEG


OPTIMAL WEIGHT DESIGN OF MAIN VERTICAL MEMBER STARTS
----------------------------------------------------

(QUESTION WHAT IS VALUE OF PENALTY PARAMETER) >1.0

(QUESTION WHAT IS VALUE OF EXPONENT) >2.0

(QUESTION WHAT IS VALUE OF CONSTANT) >10.0

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 1.4987618
          INTERNAL DIAMETER 0.89604976

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 2.0670265
          INTERNAL DIAMETER 1.3042937

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 2.8891400
          INTERNAL DIAMETER 1.7623754
=====================================================

DESIGNED DIMENSIONS OF MAIN VERTICAL MAMBER IN inch
                         EXTERNAL DIAMETER  2.8891400
                         INTERNAL DIAMETER  1.7623754
=====================================================


DESIGNING ASCESSORIES OF LANDING LEG
====================================

               DESIGNED DIMENSIONS OF CE
                         INTERNAL DIAMETER 1.2154772
                         EXTERNAL DIAMETER 2.4309545
               DESIGNED DIMENSIONS OF ED
                         INTERNAL DIAMETER 2.3081430
                         EXTERNAL DIAMETER 3.4604842


DESIGNED JACK-STROKE 2.5658706 FEET
               DESIGN OF BRAKES
               =================

KINETIC ENERGY THAT HAS TO BE ABSORBED BY BRAKES IS 495000.0

(QUESTION PLEASE GIVE THE VALUE OF THE GROUND FRICTION COEFFICIENT WITHIN THE
R
ANGE 0.25 TO 0.79999999) >0.45
               FINDING FORCE REQUIRED TO BRAKE STOP THE VEHICLE AFTER LANDING
```

```
.................................
SYSTEM RATING FOR BRAKE TYPES
................................

------------------------------------------------------------------------------------------
   BRAKE TYPE                   SYS.RATING VALUE                       SHORT FORM
------------------------------------------------------------------------------------------

  FOR THE SYSTEM TO CONTINUE ITS OWN DESIGN                          CON
  SHOE BRAKE                    1.9999997                                 SHOE
  DRUM BRAKE                    0.99999980                                 DRUM
  DISC BRAKE                    80.0                                      DISC
  NO BRAKING                    0.99999990E-1                                 NO-BR
  PARACHUTE BRAKE               0.99999990E-1                             PARA
------------------------------------------------------------------------------------------

(QUESTION PLEASE TYPE YOUR OPINION FOR BRAKE SELECTION) >DISC

(QUESTION PLEASE SPECIFY FRICTION COEFFICIENT OF BRAKING MATERIAL) >0.35

NO OF FRICTION SURFACES IS    1
NO OF FRICTION PLATES     1

YES
Should I try for another answer (Y/N):>N

OK
<10>RECORDFILE

RECORD FILE DSK: SS1 CLOSED 05-FEB-88 21:52:42
```

```
================================================================
          DESIGN DETAIL OF UNDER CARRIAGE
================================================================
          DESIGN NUMBER -----------  DS2
----------------------------------------------------------------
           PURPOSE OF THE AIRCRAFT -----  A4
----------------------------------------------------------------
          WEIGHT OF THE A/C -----  16500
          TYPE OF LANDING GEAR ----  PN
          TYPE OF LANDING LEG ----- RETRACTABLE  TYPE
----------------------------------------------------------------
          LOCATION DETAILS
----------------------------------------------------------------
          WHEEL BASE ------  12.768941 feet
          WHEEL TRACK -----  10.368749 feet
================================================================
           AUXILIARY LEG UNIT DETAILS ......
================================================================
           AUXILIARY WHEEL DETAILS.......
----------------------------------------------------------------
           AUX-WHEEL PRESSURE --- 101.66666  psi
           TYRE DIAMETER  ---- 18.0    inches
           TYRE WIDTH ----      5.6200000   inches
           RIM DIAMETER -----  8.0   inches
           AXLE DIAMETER ---- 1.3329111   inches
           NUMBER OF BOLTS ------ 8
           DIAMETER OF BOLT ------ 0.34813969   inches
           WEB THICKNESS ----- 0.22893568  inches
----------------------------------------------------------------
           AUXILIARY WHEEL LEG DETAILS.........
----------------------------------------------------------------
           SHOCK ABSORBER ---- PNUEMATIC
           HEIGHT OF LEG -----  4.1666666feet
           EXTERNAL DIAMETER ---- 1.1313690  inches
           INTERNAL DIAMETER ----0.69960466  inches
           ASCESSORIES DETAILS -----
           BRACE ONE ---
                    LENGTH ---- 23.745075  inches
                    EXTERNAL DIAMETER ----0.90849655  inches
                    INTERNAL DIAMETER ----0.45424827  inches
           BRACE TWO ----
                    LENGTH ----  38.489719  inches
                    EXTERNAL DIAMETER ----  1.2932524  inches
                    INTERNAL DIAMETER ----  0.86259940  inches
           JACK STROKE ----  2.2674881feet
           RIM FLANGE THICKNESS -- 0.22893568   inches
================================================================
               MAIN LEG UNIT DETAILS .....
================================================================
           MAIN WHEEL DETAILS......
----------------------------------------------------------------
           MAIN WHEEL PRESSURE ----  74.842104  psi
           TYRE DIAMETER ----  32.199995    inches
           TYRE WIDTH ----  9.1000000    inches
           RIM DIA OF THE MAIN WHEEL ----  15.5   inches
           AXLE DIA OF THE MAIN WHEEL ----  2.6550889   inches
           NUMBER OF BOLTS -----  12
           DIAMETER OF BOLT ----  0.34023525  inches
           WEB THICKNESS ----  0.16928348  inches
----------------------------------------------------------------
          MAIN WHEEL LEG DETAILS ------
----------------------------------------------------------------
           SHOCK ABSORBER ----  OLEO-PNUEMATIC
           HEIGHT OF LEG ----4.3541666feet
           EXTERNAL DIAMETER ----  2.8891400  inches
           INTERNAL DIAMETER ----  1.7623754  inches
           ASCESSORIES DETAILS ----
           BRACE ONE ----
                    LENGTH ----  31.904328  inches
                    EXTERNAL DIAMETER ----  2.4309545  inches
                    INTERNAL DIAMETER ----  1.2154772  inches
           BRACE TWO ----
                    LENGTH ----  43.555356  inches
                    EXTERNAL DIAMETER ----  3.4604842  inches
                    INTERNAL DIAMETER ----  2.3081430  inches
           JACK STROKE ----  2.5658706  inches
           FLANGE THICKNESS OF THE RIM ----0.16928348    inches
----------------------------------------------------------------
           TYPE OF THE BRAKEING SYSTEM ---  DISC ---
 ===============================================================
                     ......END OF DETAILS .....
================================================================

NIL
```

SAMPLE RUN-3

```
RECORD FILE DSK: SS1 OPENED 05-FEB-88 22:09:45
NIL
<9>(GOAL (START))


               *************************************
               welcome to tne UNDERCARRIGE DESIGNER
               *************************************


          -------------------------------------------------------------
          I will now proceed to ask you series of questions pertaining
          to the design which you want to perform. If you donot
          understand the question type  WHAT  for the explanation of the
          question.
          -------------------------------------------------------------

TYPE  CON  FOR CONTINUE>CON

(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >16500

=====================================================
1 AGRICULTURAL PURPOSE                  TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER        TYPE A2
3 TRAINER 1 2 SEATER                    TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER        TYPE A4
5 UTILITY AIRCRAFT                      TYPE A5
6 LIGHT,AMETURE A/C                     TYPE A6
7 FIGHTERS                              TYPE A7
8 PASSENGER,AIRSERVICE                  TYPE A8
9 CARGC TRANSPORT                       TYPE A9
10 SPORTS PLANES                        TYPE A10
==========================================================

(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A4

==============================================================================

               OLD DESIGN DETAIL
==============================================================================
          DESIGN NO =           DS2

          PURPOSE OF THE A/C             A4
          WEIGHT OF THIS A/C  =          16500

LANDING GEAR TYPE    PN

LANDING LEG TYPE     RETRACTABLE

----------------------------------------------------------------------------
LOCATION DETAIL ...
               WHEEL BASE = 12.768941                WHEEL TRACK = 10.368749
-------------------------------------------------------------------------

               AUX-WHEEL DETAIL
               ...................
     PRESSURE  = 101.66666  psi                    TYRE DIA = 18.0  inchs
      TYRE WIDTH = 5.6200000  inchs                      RIM DIA = 8.0
     AXEL DIA = 1.3329111 WHEEL FLANGE THICKNESS = 0.22893568
     NUMBER OF BOLTS = 8    DIAMETER OF BOLT = 0.34813969inch
     WEB THICKNESS = 0.22893568     SHOCK ABSORBER = PNUEMATIC
     HEIGHT OF LEG = 4.1666666feet
     DETAILS OF LEG ====
     EXTERNAL DIAMETER =1.1313689inch     INTERNAL DIAMETER =0.69960466inch
     ASCESSORIES DETAILS ======
     BRACE ONE =====                     BRACE TWO =====
     LENGTH = 23.745074inch               LENGTH = 38.489718inch
     EXTERNAL DIAMETER = 0.90849655inch     EXTERNAL DIAMETER = 1.2932524inch
     INTERNAL DIAMETER = 0.45424827inch     INTERNAL DIAMETER = 0.86259940inch
     JACK STROKE = 2.2674880feet

TYPE   CON     FOR CONTINUE >CON
CON
-------------------------------------------------------------------------
```

```
              MAIN WHEEL DETAIL
              .........................

      PRESSURE = 74.842103   psi                    TYRE DIA = 32.199995  inchs
       TYRE WIDTH = 9.1000000  inchs                         RIM DIA = 15.5
      AXLE DIA = 2.6550889  inchs         WHEEL FLANGE THICKNESS = 0.16928348
      NUMBER OF BOLTS = 12     DIAMETER OF BOLT = 0.34023525inch
      WEB THICKNESS = 0.16928348     SHOCK ABSORBER = OLEO-PNUEMATIC
      HEIGHT OF LEG = 4.3541666feet
      DETAILS OF LEG ====
      EXTERNAL DIAMETER =2.8891400inch      INTERNAL DIAMETER =1.7623753inch
      ASCESSORIES DETAILS ======
      BRACE ONE =====                      BRACE TWO =====
      LENGTH = 31.904328inch                LENGTH = 43.555356inch
      EXTERNAL DIAMETER = 2.4309545inch      EXTERNAL DIAMETER = 3.4604842inch
      INTERNAL DIAMETER = 1.2154771inch      INTERNAL DIAMETER = 2.3081429inch
      JACK STROKE = 2.5658706feet
------------------------------------------------------------------------------
              TYPE OF BRAKING SYSTEM......   DISC
==============================================================================

TYPE   CON      FOR CONTINUE >CCN

 TYPE THE OPTION AS INDICATED   BELOW
------------------------------------------------------------------------------
          OPTION                         SHORT FORM TO BE TYPED
--------------------------------------------------------------------------------
-

          DESIGN COMPLETELY ACCEPTABLE                    OK  <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                 ALTER   <THAT DESIGN NO >

          FURTHER SEARCH DESIRED                     SEARCH < XX >
          A NEW DESIGN DESIRED                       NEW    <NEW DESIGN NO>
=============================================================================

(QUESTION PLEASE TYPE YOUR OPINION NOW) >OK DS2

(QUESTION PLEASE TYPE NEW DESIGN NUMBER) >DS3

YES
should I try for another answer (Y/N):>N

OK
<10>RECORDFILE

RECORD FILE DSK: SS1 CLOSED 05-FEB-88 22:12:01
```

```
:===============================================================
         DESIGN DETAIL OF UNDER CARRIAGE
:===============================================================
         DESIGN NUMBER -----------  DS3
----------------------------------------------------------------
          PURPOSE OF THE AIRCRAFT -----  A4
----------------------------------------------------------------
         WEIGHT OF THE A/C -----  16500
         TYPE OF LANDING GEAR ----  PN
         TYPE OF LANDING LEG ----- RETRACTABLE  TYPE
----------------------------------------------------------------
         LOCATION DETAILS
----------------------------------------------------------------
         WHEEL BASE ------  12.768941 feet
         WHEEL TRACK -----  10.368749 feet
================================================================
          AUXILIARY LEG UNIT DETAILS ......
================================================================
          AUXILIARY WHEEL DETAILS.......
----------------------------------------------------------------
          AUX-WHEEL PRESSURE --- 101.66666  psi
          TYRE DIAMETER  ---- 18.0  inches
          TYRE WIDTH ----     5.6200000  inches
          RIM DIAMETER -----  8.0  inches
          AXLE DIAMETER ---- 1.3329111  inches
          NUMBER OF BOLTS ------ 8
          DIAMETER OF BOLT ------ 0.34813969  inches
          WEB THICKNESS ----- 0.22893568   inches
----------------------------------------------------------------
          AUXILIARY WHEEL LEG DETAILS.........
----------------------------------------------------------------
          SHOCK ABSORBER ---- PNUEMATIC
          HEIGHT OF LEG -----  4.1666666feet
          EXTERNAL DIAMETER ---- 1.1313689  inches
          INTERNAL DIAMETER ----0.69960466  inches
          ASCESSORIES DETAILS -----
          BRACE ONE ---
                   LENGTH ---- 23.745074  inches
                   EXTERNAL DIAMETER ----0.90849655  inches
                   INTERNAL DIAMETER ----0.45424827  inches
          BRACE TWO ----
                   LENGTH ----  38.489718  inches
                   EXTERNAL DIAMETER ----  1.2932524  inches
                   INTERNAL DIAMETER ----  0.86259940  inches
          JACK STROKE ----  2.2674880feet
          RIM FLANGE THICKNESS -- 0.22893568  inches
================================================================
              MAIN LEG UNIT DETAILS .....
================================================================
          MAIN WHEEL DETAILS......
----------------------------------------------------------------
          MAIN WHEEL PRESSURE ----  74.842103  psi
          TYRE DIAMETER ----  32.199995    inches
          TYRE WIDTH ----  9.1000000  inches
          RIM DIA OF THE MAIN WHEEL ----  15.5  inches
          AXLE DIA OF THE MAIN WHEEL ----  2.6550889  inches
          NUMBER OF BOLTS -----  12
          DIAMETER OF BOLT ----  0.34023525  inches
          WEB THICKNESS ----  0.16928348  inches
----------------------------------------------------------------
         MAIN WHEEL LEG DETAILS ------
----------------------------------------------------------------
          SHOCK ABSORBER ----  OLEO-PNUEMATIC
          HEIGHT OF LEG ----4.3541666feet
          EXTERNAL DIAMETER ----  2.8891400  inches
          INTERNAL DIAMETER ----  1.7623753  inches
          ASCESSORIES DETAILS ----
          BRACE ONE ----
                   LENGTH ----  31.904328  inches
                   EXTERNAL DIAMETER ----  2.4309545  inches
                   INTERNAL DIAMETER ----  1.2154771  inches
          BRACE TWO ----
                   LENGTH ----  43.555356  inches
                   EXTERNAL DIAMETER ----  3.4604842  inches
                   INTERNAL DIAMETER ----  2.3081429  inches
          JACK STROKE ----  2.5658706  inches
          FLANGE THICKNESS OF THE RIM ----0.16928348  inches
----------------------------------------------------------------
          TYPE OF THE BRAKEING SYSTEM ---  DISC ---
 ===============================================================
                  ......END OF DETAILS .....
================================================================

NIL
```

SAMPLE RUN-4

```
RECORD FILE DSK: SS1 OPENED 06-FEB-88 04:20:40
NIL
<9>(GOAL (START))


               *************************************
               Welcome to the UNDERCARRIGE DESIGNER
               *************************************


          ------------------------------------------------------------
          I will now proceed to ask you series of questions pertaining
          to the design which you want to perform. If you donot
          understand the question type  WHAT  for the explanation of the
          question.
          ------------------------------------------------------------

TYPE  CON  FOR CONTINUE>CON

(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >16500

=====================================================
1 AGRICULTURAL PURPUSE                  TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER        TYPE A2
3 TRAINER 1 2 SEATER                    TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER        TYPE A4
5 UTILITY AIRCRAFT                      TYPE A5
6 LIGHT,AMETURE A/C                     TYPE A6
7 FIGHTERS                              TYPE A7
8 PASSENGER,AIRSERVICE                  TYPE A8
9 CARGC TRANSPORT                       TYPE A9
10 SPORTS PLANES                        TYPE A10
==========================================================

(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A4
============================================================================:

               OLD DESIGN DETAIL
============================================================================:
          DESIGN NO =                DS3
          PURPOSE OF THE A/C                 A4
          WEIGHT OF THIS A/C  =               16500
LANDING GEAR TYPE    PN

LANDING LEG TYPE     RETRACTABLE

---------------------------------------------------------------------------
LOCATION DETAIL ...
               WHEEL BASE = 12.768941                 WHEEL TRACK = 10.368749
--------------------------------------------------------------------

               AUX-WHEEL DETAIL
               ....................
     PRESSURE  = 101.66666  psi                      TYRE DIA = 18.0  inchs
      TYRE WIDTH = 5.6200000  inchs                        RIM DIA = 8.0
     AXEL DIA = 1.3329111 WHEEL FLANGE THICKNESS = 0.22893568
     NUMBER OF BOLTS = 8     DIAMETER OF BOLT = 0.34813969inch
     WEB THICKNESS = 0.22893568      SHOCK ABSORBER = PNUEMATIC
     HEIGHT OF LEG = 4.1666666feet
     DETAILS OF LEG ====
     EXTERNAL DIAMETER =1.1313689inch     INTERNAL DIAMETER =0.69960466inch
     ASCESSORIES DETAILS ======
     BRACE ONE =====                     BRACE TWO =====
     LENGTH = 23.745074inch               LENGTH = 38.489717inch
     EXTERNAL DIAMETER = 0.90849655inch     EXTERNAL DIAMETER = 1.2932524inch
     INTERNAL DIAMETER = 0.45424827inch     INTERNAL DIAMETER = 0.86259940inch
     JACK STROKE = 2.2674880feet

TYPE   CON      FOR CONTINUE >CON
--------------------------------------------------------------------
               MAIN WHEEL DETAIL
               .........................

     PRESSURE = 74.842103   psi                   TYRE DIA = 32.199995  inchs
      TYRE WIDTH = 9.1000000  inchs                    RIM DIA = 15.5
     AXLE DIA = 2.6550889  inchs        WHEEL FLANGE THICKNESS = 0.16928348
     NUMBER OF BOLTS = 12     DIAMETER OF BOLT = 0.34023525inch
     WEB THICKNESS = 0.16928348      SHOCK ABSORBER = OLEO-PNUEMATIC
     HEIGHT OF LEG = 4.3541666feet
```

```
    DETAILS OF LEG ====
    EXTERNAL DIAMETER =2.8891400inch      INTERNAL DIAMETER =1.7623753inch
    ASCESSORIES DETAILS ======
    BRACE ONE =====                      BRACE TWO =====
    LENGTH = 31.904328inch                LENGTH = 43.555356inch
    EXTERNAL DIAMETER = 2.4309545inch      EXTERNAL DIAMETER = 3.4604842inch
    INTERNAL DIAMETER = 1.2154771inch      INTERNAL DIAMETER = 2.3081429inch
    JACK STROKE = 2.5658706feet
---------------------------------------------------------------------------
              TYPE OF BRAKING SYSTEM......   DISC
===========================================================================

TYPE   CON      FOR CONTINUE >CON
 TYPE THE OPTION AS INDICATED   BELOW
---------------------------------------------------------------------------
          OPTION                        SHORT FORM TO BE TYPED
------------------------------------------------------------------------------

        DESIGN COMPLETELY ACCEPTABLE                        OK   <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                    ALTER   <THAT DESIGN NO >

        FURTHER SEARCH DESIRED                          SEARCH < XX >
        A NEW DESIGN DESIRED                            NEW   <NEW DESIGN NO>
==========================================================================

(QUESTION PLEASE TYPE YOUR OPINION NOW) >SEARCH XX
=============================================================================
              OLD DESIGN DETAIL
=============================================================================
        DESIGN NO =            DS2

        PURPOSE OF THE A/C               A4
        WEIGHT OF THIS A/C   =            16500

LANDING GEAR TYPE     PN

LANDING LEG TYPE      RETRACTABLE

-------------------------------------------------------------------------
LOCATION DETAIL ...
              WHEEL BASE = 12.768941                    WHEEL TRACK = 10.368749
--------------------------------------------------------------------

              AUX-WHEEL DETAIL
              ....................
     PRESSURE  = 101.66666  psi                   TYRE DIA = 18.0  inchs
      TYRE WIDTH = 5.6200000  inchs                    RIM DIA = 8.0
     AXEL DIA = 1.3329111 WHEEL FLANGE THICKNESS = 0.22893568
     NUMBER OF BOLTS = 8    DIAMETER OF BOLT = 0.34813969inch
     WEB THICKNESS = 0.22893568     SHOCK ABSORBER = PNUEMATIC
     HEIGHT OF LEG = 4.1666666feet
     DETAILS OF LEG ====
     EXTERNAL DIAMETER =1.1313689inch     INTERNAL DIAMETER =0.69960466inch
     ASCESSORIES DETAILS ======
     BRACE ONE =====                      BRACE TWO =====
     LENGTH = 23.745074inch                LENGTH = 38.489717inch
     EXTERNAL DIAMETER = 0.90849655inch      EXTERNAL DIAMETER = 1.2932524inch
     INTERNAL DIAMETER = 0.45424827inch      INTERNAL DIAMETER = 0.86259940inch
     JACK STROKE = 2.2674880feet

TYPE   CON      FOR CONTINUE >CON
------------------------------------------------------------------

              MAIN WHEEL DETAIL
              ..........................

     PRESSURE = 74.842103   psi                  TYRE DIA = 32.199995  inchs
      TYRE WIDTH = 9.1000000  inchs                     RIM DIA = 15.5
     AXLE DIA = 2.6550889  inchs          WHEEL FLANGE THICKNESS = 0.16928348
     NUMBER OF BOLTS = 12     DIAMETER OF BOLT = 0.34023525inch
     WEB THICKNESS = 0.16928348     SHOCK ABSORBER = OLEO-PNUEMATIC
     HEIGHT OF LEG = 4.3541666feet
     DETAILS OF LEG ====
     EXTERNAL DIAMETER =2.8891400inch     INTERNAL DIAMETER =1.7623753inch
     ASCESSORIES DETAILS ======
     BRACE ONE =====                      BRACE TWO =====
     LENGTH = 31.904328inch                LENGTH = 43.555356inch
     EXTERNAL DIAMETER = 2.4309545inch      EXTERNAL DIAMETER = 3.4604842inch
     INTERNAL DIAMETER = 1.2154771inch      INTERNAL DIAMETER = 2.3081429inch
     JACK STROKE = 2.5658706feet
---------------------------------------------------------------------------
              TYPE OF BRAKING SYSTEM......   DISC
===========================================================================
TYPE   CON     FOR CONTINUE >CON
  TYPE THE OPTION AS INDICATED   BELOW
---------------------------------------------------------------------------
          OPTION                         SHORT FORM TO BE TYPED
-----------------------------------------------------------------------------

         DESIGN COMPLETELY ACCEPTABLE                        OK  <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                     ALTER   <THAT DESIGN NO >

         FURTHER SEARCH DESIRED                          SEARCH < XX >

         A NEW DESIGN DESIRED                            NEW   <NEW DESIGN NO>
===========================================================================

(QUESTION PLEASE TYPE YOUR OPINION NOW) >NEW DS4

************************************************
DESIGN WILL BE DONE FOR RETRACTABLE LANDING GEAR
************************************************

.............................................
DESIGN WILL BE DONE FOR NOSEWHEEL-TYPE
...................................

-----------------------------------------------
     UNDERCARRIAGE LOCATION DETAILS

FORE LOCATION                11.236668  feet

AFT LOCATION                 1.5322729  feet

WHEEL BASE                   12.768941  feet

WHEEL TRACK                  10.368749  feet

------------------------------------------------

MEDIUM CLASS AC

********************
PARTS DESIGN
********************

               DESIGN OF AUX-WHEEL
               ===================
AUX-WHEEL PRESSURE WILL BE CALCULATED

AUX-WHEEL TYRE SELECTION
         NUMBER OF TYRES IN AUX-WHEEL 1.0
STATIC LOAD ON AUX-WHEEL 3000.0
PRESSURE FINAL =  101.66666

AUX-WHEEL  DETAILS
                  DIAMETER OF TYRE        18.0
                  TYRE WIDTH               5.6200000
                   WHEEL RIM DIAMETER     8.0

               -------------------------------
               DETAILED DESIGN OF AUX-WHEEL PARTS
               ------------------------------
WHEEL WILL BE DESIGNED AS MODERN SPLIT TYPE WHEEL
FINDING AXLE DIA
HOLLOW AXLE OF OUTER DIA  1.3329111
FLANGE THICKNESS = 0.22893568
DESIGNING FASTENING BOLTS
MATERIAL USED OPEN-HEARTH NICKEL STEEL

NUMBER OF BOLTS 8.0
DIA OF BOLT 0.34813969
               FINDING MAXIMUM STRESSES IN WEB OF AUX-WHEEL
               ------------------------------------------
ASSUMING THICKNESS OF WEB EQUALS TO THICKNESS OF FLANGE

          STRESSES CALCULATED AS
                         MAXIMUM RADIAL STRESS -6135.4393
                         MAXIMUM TANGENTIAL STRESS 17204.034
                         MAXIMUM SHEAR STRESS 777.04625

-----------------------------------------------
STRESSES CALCULATED ARE WITH IN THE LIMITS
THICKNESS OF WEB OF AUX-WHEEL 0.22893568
-----------------------------------------------
```

```
CHECKING ABOVE DESIGNED THICKNESS FOR A TORQUE

MAXIMUM SHEAR STRESS DUE TO PURE TORQUE 2064.5896

ABOVE CALCULATED SHEAR STRESS IS WITH IN THE LIMTIS
FINAL WEB THICKNESS  0.22893568 inch

               DESIGN OF AUX-WHEEL LEG
               =======================

HEIGHT OF AUX-WHEEL LEG 4.1666666

PNUEMATIC TYPE OF SHOCK ABSORBER

SHOCK ABSORBER TRAVEL 0.79895253 FT

ANALYSING THE LANDING LEG

OPTIMAL WEIGHT DESIGN OF MAIN VERTICAL MEMBER STARTS
----------------------------------------------------

DESIGNED DIMENSIONS
         EXTERNAL DIAMETER 0.59853744
         INTERNAL DIAMETER 0.41170996

DESIGNED DIMENSIONS
         EXTERNAL DIAMETER 0.66103731
         INTERNAL DIAMETER 0.41768303

DESIGNED DIMENSIONS
         EXTERNAL DIAMETER 0.78270285
         INTERNAL DIAMETER 0.46179468

DESIGNED DIMENSIONS
         EXTERNAL DIAMETER 1.1313690
         INTERNAL DIAMETER 0.69960466

=====================================================

DESIGNED DIMENSIONS OF MAIN VERTICAL MAMBER IN inch
                      EXTERNAL DIAMETER  1.1313690
                      INTERNAL DIAMETER  0.69960466
=====================================================

DESIGNING ASCESSORIES OF LANDING LEG
====================================

              DESIGNED DIMENSIONS OF CE
                      INTERNAL DIAMETER 0.45424827
                      EXTERNAL DIAMETER 0.90849655
              DESIGNED DIMENSIONS OF ED
                      INTERNAL DIAMETER 0.86259940
                      EXTERNAL DIAMETER 1.2932524


DESIGNED JACK-STROKE 2.2674881 FEET

              DESIGN OF MAIN-WHEEL
              ====================

MAIN-WHEEL PRESSURE WILL BE CALCULATED

MAIN-WHEEL TYRE SELECTION
         NUMBER OF TYRES IN MAIN-WHEEL 2.0

STATIC LOAD ON MAIN-WHEEL 7260.0

PRESSURE FINAL =  74.842104

MAIN-WHEEL  DETAILS
                 DIAMETER OF TYRE        32.199995
                 TYRE WIDTH               9.1000000
                  WHEEL RIM DIAMETER     15.5

              ----------------------------------
              DETAILED DESIGN OF MAIN-WHEEL PARTS
              ----------------------------------
WHEEL WILL BE DESIGNED AS MODERN SPLIT TYPE WHEEL

FINDING AXLE DIA

HOLLOW AXLE OF OUTER DIA  2.6550889
FLANGE THICKNESS = 0.16928348
```

```
DESIGNING FASTENING BOLTS
MATERIAL USED OPEN-HEARTH NICKEL STEEL

NUMBER OF BOLTS 12.0
DIA OF BOLT 0.34023525

                   FINDING MAXIMUM STRESSES IN WEB OF MAIN-WHEEL
                   ---------------------------------------------
ASSUMING THICKNESS OF WEB EQUALS TO THICKNESS OF FLANGE

             STRESSES CALCULATED AS
                              MAXIMUM RADIAL STRESS -9620.1287
                              MAXIMUM TANGENTIAL STRESS 21851.161
                              MAXIMUM SHEAR STRESS 3537.1483

-----------------------------------------------------------
STRESSES CALCULATED ARE WITH IN THE LIMITS
THICKNESS OF WEB OF MAIN-WHEEL 0.16928348
-----------------------------------------------------------

CHECKING ABOVE DESIGNED THICKNESS FOR A TORQUE

MAXIMUM SHEAR STRESS DUE TO PURE TORQUE 10279.126

ABOVE CALCULATED SHEAR STRESS IS WITH IN THE LIMITS
FINAL WEB THICKNESS  0.16928348 inch

                   DESIGN OF MAIN-WHEEL LEG
                   ===========================

HEIGHT OF MAIN-WHEEL LEG 4.3541666

PLEASE GIVE YOUR WEIGHTAGE FOR THE FOLLOWING
SPRING CHARACTORS IN THE RANGE OF 1 TO 10 . 10 BEING MAXIMUM

  1  SIMPLICITY OF SHOCK ABSORBER
  2  WEIGTH OF SHOCK-ABSORBER
  3  EFFICIENCY OF ABSORBER
  4  RELIABILITY OF ABSORBER
(QUESTION TYPE YOUR ANSWERS WITH A BLANK SEPERATING THEM) >6 7 8 4

FOR MAIN WHEEL OLEO-PNUEMATIC SHOCK ABSORBER IS  USED

SHOCK ABSORBER TRAVEL 0.69474133 FT

ANALYSING THE LANDING LEG


OPTIMAL WEIGHT DESIGN OF MAIN VERTICAL MEMBER STARTS
------------------------------------------------------------

DESIGNED DIMENSIONS
            EXTERNAL DIAMETER 1.4987618
            INTERNAL DIAMETER 0.89604976

DESIGNED DIMENSIONS
            EXTERNAL DIAMETER 2.0670265
            INTERNAL DIAMETER 1.3042937

DESIGNED DIMENSIONS
            EXTERNAL DIAMETER 2.8891400
            INTERNAL DIAMETER 1.7623754

==============================================================

DESIGNED DIMENSIONS OF MAIN VERTICAL MAMBER IN inch
                              EXTERNAL DIAMETER  2.8891400
                              INTERNAL DIAMETER  1.7623754
==============================================================



DESIGNING ASCESSORIES OF LANDING LEG
========================================

                   DESIGNED DIMENSIONS OF CE
                              INTERNAL DIAMETER 1.2154772
                              EXTERNAL DIAMETER 2.4309545
                   DESIGNED DIMENSIONS OF ED
                              INTERNAL DIAMETER 2.3081430
                              EXTERNAL DIAMETER 3.4604842



DESIGNED JACK-STROKE 2.5658706 FEET
```

```
              DESIGN OF BRAKES
              ================

KINETIC ENERGY THAT HAS TO BE ABSORBED BY BRAKES IS 495000.0
              FINDING FORCE REQUIRED TO BRAKE STOP THE VEHICLE AFTER LANDING

.................................
SYSTEM RATING FOR BRAKE TYPES
..............................

----------------------------------------------------------------------
   BRAKE TYPE                 SYS.RATING VALUE             SHORT FORM
----------------------------------------------------------------------

  FOR THE SYSTEM TO CONTINUE ITS OWN DESIGN               CON
  SHOE BRAKE                  1.9999997                       SHOE
  DRUM BRAKE                  0.99999980                       DRUM
  DISC BRAKE                  80.0                            DISC
  NO BRAKING                  0.99999990E-1                       NO-BR
  PARACHUTE BRAKE             0.99999990E-1                   PARA
----------------------------------------------------------------------

NO OF FRICTION SURFACES IS    1
NO OF FRICTION PLATES    1

YES
Should I try for another answer (Y/N):>N

OK
<10>RECORDFILE

RECORD FILE DSK: SS1 CLOSED 06-FEB-88 04:24:31
```

```
================================================================
          DESIGN DETAIL OF UNDER CARRIAGE
================================================================
          DESIGN NUMBER -----------  DS4
----------------------------------------------------------------
           PURPOSE OF THE AIRCRAFT -----  A4
----------------------------------------------------------------
          WEIGHT OF THE A/C -----  16500
          TYPE OF LANDING GEAR ----  PN
          TYPE OF LANDING LEG ----- RETRACTABLE  TYPE
----------------------------------------------------------------
          LOCATION DETAILS
----------------------------------------------------------------
          WHEEL BASE ------  12.768941 feet
          WHEEL TRACK -----  10.368749 feet
================================================================
           AUXILIARY LEG UNIT DETAILS ......
================================================================
           AUXILIARY WHEEL DETAILS.......
----------------------------------------------------------------
           AUX-WHEEL PRESSURE --- 101.66666  psi
           TYRE DIAMETER  ---- 18.0  inches
           TYRE WIDTH ----      5.6200000  inches
           RIM DIAMETER -----  8.0  inches
           AXLE DIAMETER ---- 1.3329111  inches
           NUMBER OF BOLTS ------ 8
           DIAMETER OF BOLT ------ 0.34813969  inches
           WEB THICKNESS ----- 0.22893568   inches
----------------------------------------------------------------
           AUXILIARY WHEEL LEG DETAILS.........
----------------------------------------------------------------
           SHOCK ABSORBER ---- PNUEMATIC
           HEIGHT OF LEG -----  4.1666666feet
           EXTERNAL DIAMETER ---- 1.1313690  inches
           INTERNAL DIAMETER ----0.69960466  inches
           ASCESSORIES DETAILS -----
           BRACE ONE ---
                     LENGTH ---- 23.745075  inches
                     EXTERNAL DIAMETER ----0.90849655  inches
                     INTERNAL DIAMETER ----0.45424827  inches
           BRACE TWO ----
                     LENGTH ----  38.489719  inches
                     EXTERNAL DIAMETER ----  1.2932524  inches
                     INTERNAL DIAMETER ----  0.86259940  inches
           JACK STROKE ----  2.2674881feet
           RIM FLANGE THICKNESS -- 0.22893568  inches
================================================================
               MAIN LEG UNIT DETAILS .....
================================================================
           MAIN WHEEL DETAILS......
----------------------------------------------------------------
           MAIN WHEEL PRESSURE ----  74.842104  psi
           TYRE DIAMETER ----  32.199995    inches
           TYRE WIDTH ----  9.1000000  inches
           RIM DIA OF THE MAIN WHEEL ----  15.5  inches
           AXLE DIA OF THE MAIN WHEEL ----  2.6550889  inches
           NUMBER OF BOLTS -----  12
           DIAMETER OF BOLT ----  0.34023525  inches
           WEB THICKNESS ----  0.16928348  inches
----------------------------------------------------------------
          MAIN WHEEL LEG DETAILS ------
----------------------------------------------------------------
           SHOCK ABSORBER ----  OLEO-PNUEMATIC
           HEIGHT OF LEG ----4.3541666feet
           EXTERNAL DIAMETER ----  2.8891400  inches
           INTERNAL DIAMETER ----  1.7623754  inches
           ASCESSORIES DETAILS ----
           BRACE ONE ----
                     LENGTH ----  31.904328  inches
                     EXTERNAL DIAMETER ----  2.4309545  inches
                     INTERNAL DIAMETER ----  1.2154772  inches
           BRACE TWO ----
                     LENGTH ----  43.555356  inches
                     EXTERNAL DIAMETER ----  3.4604842  inches
                     INTERNAL DIAMETER ----  2.3081430  inches
           JACK STROKE ----  2.5658706  inches
           FLANGE THICKNESS OF THE RIM ----0.16928348  inches
----------------------------------------------------------------
           TYPE OF THE BRAKEING SYSTEM ---  DISC ---
================================================================
                  ......END OF DETAILS .....
================================================================

NIL
```

SAMPLE RUN-5

```
RECORD FILE DSK: SS1 OPENED 06-FEB-88 21:09:13
NIL
<9>(GOAL (START))


                ****************************************
                Welcome to the UNDERCARRIGE DESIGNER
                ****************************************


          ------------------------------------------------------
          I will now proceed to ask you series of questions pertaining
          to the design which you want to perform. If you donot
          understand the question type  WHAT  for the explanation of the
          question.
          ------------------------------------------------------

TYPE  CON  FOR CONTINUE>CON

(QUESTION PLEASE SPECIFY THE WEIGHT OF THE AIRCRAFT IN POUNDS) >16500

================================================
1 AGRICULTURAL PURPOSE                  TYPE  A1
2 LIGHT TRANSPORT 1 2 3 4 SEATER        TYPE A2
3 TRAINER 1 2 SEATER                    TYPE A3
4 EXECUTIVE TRANSPORT 4-8 SEATER        TYPE A4
5 UTILITY AIRCRAFT                      TYPE A5
6 LIGHT,AMETURE A/C                     TYPE A6
7 FIGHTERS                              TYPE A7
8 PASSENGER,AIRSERVICE                  TYPE A8
9 CARGO TRANSPORT                       TYPE A9
10 SPORTS PLANES                        TYPE A10
=====================================================

(QUESTION PLEASE SELECT FROM THE ABOVE TABLE AND ANSWER) >A4

======================================================================

              OLD DESIGN DETAIL
======================================================================
          DESIGN NO =            DS4
          PURPOSE OF THE A/C             A4
          WEIGHT OF THIS A/C  =           16500
LANDING GEAR TYPE    PN

LANDING LEG TYPE     RETRACTABLE

-------------------------------------------------------------------
LOCATION DETAIL ...
              WHEEL BASE = 12.768941              WHEEL TRACK = 10.368749
---------------------------------------------------------------
              AUX-WHEEL DETAIL
              ..................
    PRESSURE  = 101.66666  psi                 TYRE DIA = 18.0  inchs
     TYRE WIDTH = 5.6200000  inchs                  RIM DIA = 8.0
    AXEL DIA = 1.3329111 WHEEL FLANGE THICKNESS = 0.22893568
    NUMBER OF BOLTS = 8    DIAMETER OF BOLT = 0.34813969inch
    WEB THICKNESS = 0.22893568     SHOCK ABSORBER = PNUEMATIC
    HEIGHT OF LEG = 4.1666666feet
    DETAILS OF LEG ====
    EXTERNAL DIAMETER =1.1313689inch     INTERNAL DIAMETER =0.69960466inch
    ASCESSORIES DETAILS ======
    BRACE ONE =====                      BRACE TWO =====
    LENGTH = 23.745074inch                LENGTH = 38.489717inch
    EXTERNAL DIAMETER = 0.90849655inch      EXTERNAL DIAMETER = 1.2932524inch
    INTERNAL DIAMETER = 0.45424827inch      INTERNAL DIAMETER = 0.86259940inch
    JACK STROKE = 2.2674880feet

TYPE   CON     FOR CONTINUE >CON
---------------------------------------------------------------

              MAIN WHEEL DETAIL
              .........................

    PRESSURE = 74.842103   psi                 TYRE DIA = 32.199995  inchs
     TYRE WIDTH = 9.1000000  inchs                  RIM DIA = 15.5
    AXLE DIA = 2.6550889  inchs        WHEEL FLANGE THICKNESS = 0.16928348
    NUMBER OF BOLTS = 12     DIAMETER OF BOLT = 0.34023525inch
    WEB THICKNESS = 0.16928348     SHOCK ABSORBER = OLEO-PNUEMATIC
    HEIGHT OF LEG = 4.3541666feet
```

```
         DETAILS OF LEG ====
         EXTERNAL DIAMETER =2.8891400inch       INTERNAL DIAMETER =1.7623753inch
         ASCESSORIES DETAILS ======
         BRACE ONE =====                        BRACE TWO =====
         LENGTH = 31.904328inch                  LENGTH = 43.555356inch
         EXTERNAL DIAMETER = 2.4309545inch        EXTERNAL DIAMETER = 3.4604842inch
         INTERNAL DIAMETER = 1.2154771inch        INTERNAL DIAMETER = 2.3081429inch
         JACK STROKE = 2.5658706feet
----------------------------------------------------------------------------
                 TYPE OF BRAKING SYSTEM......   DISC
============================================================================

TYPE    CON      FOR CONTINUE >CON

  TYPE THE OPTION AS INDICATED   BELOW
----------------------------------------------------------------------------
            OPTION                     SHORT FORM TO BE TYPED
-------------------------------------------------------------------------------

           DESIGN COMPLETELY ACCEPTABLE                    OK   <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                    ALTER   <THAT DESIGN NO >

           FURTHER SEARCH DESIRED                       SEARCH < XX >

           A NEW DESIGN DESIRED                         NEW    <NEW DESIGN NO>
===========================================================================

(QUESTION PLEASE TYPE YOUR OPINION NOW) >SEARCH XX

===============================================================================
                 OLD DESIGN DETAIL
===============================================================================
           DESIGN NO =              DS3
           PURPOSE OF THE A/C               A4
           WEIGHT OF THIS A/C   =            16500
LANDING GEAR TYPE     PN

LANDING LEG TYPE      RETRACTABLE

---------------------------------------------------------------------------
LOCATION DETAIL ...
                 WHEEL BASE = 12.768941                   WHEEL TRACK = 10.368749
-----------------------------------------------------------------------
                 AUX-WHEEL DETAIL
                 ...................
      PRESSURE  = 101.66666  psi                    TYRE DIA = 18.0  inchs
       TYRE WIDTH = 5.6200000  inchs                      RIM DIA = 8.0
      AXEL DIA = 1.3329111 WHEEL FLANGE THICKNESS = 0.22893568
      NUMBER OF BOLTS = 8     DIAMETER OF BOLT = 0.34813969inch
      WEB THICKNESS = 0.22893568     SHOCK ABSORBER = PNUEMATIC
      HEIGHT OF LEG = 4.1666666feet
      DETAILS OF LEG ====
      EXTERNAL DIAMETER =1.1313689inch      INTERNAL DIAMETER =0.69960466inch
      ASCESSORIES DETAILS ======
      BRACE ONE =====                       BRACE TWO =====
      LENGTH = 23.745074inch                 LENGTH = 38.489717inch
      EXTERNAL DIAMETER = 0.90849655inch       EXTERNAL DIAMETER = 1.2932524inch
      INTERNAL DIAMETER = 0.45424827inch       INTERNAL DIAMETER = 0.86259940inch
      JACK STROKE = 2.2674880feet

TYPE    CON      FOR CONTINUE >CON
-----------------------------------------------------------------------

                 MAIN WHEEL DETAIL
                 .........................

      PRESSURE = 74.842103   psi                     TYRE DIA = 32.199995  inchs
       TYRE WIDTH = 9.1000000  inchs                        RIM DIA = 15.5
      AXLE DIA = 2.6550889  inchs          WHEEL FLANGE THICKNESS = 0.16928348
      NUMBER OF BOLTS = 12    DIAMETER OF BOLT = 0.34023525inch
      WEB THICKNESS = 0.16928348     SHOCK ABSORBER = OLEO-PNUEMATIC
      HEIGHT OF LEG = 4.3541666feet
      DETAILS OF LEG ====
      EXTERNAL DIAMETER =2.8891400inch      INTERNAL DIAMETER =1.7623753inch
      ASCESSORIES DETAILS ======
      BRACE ONE =====                       BRACE TWO =====
      LENGTH = 31.904328inch                 LENGTH = 43.555356inch
      EXTERNAL DIAMETER = 2.4309545inch       EXTERNAL DIAMETER = 3.4604842inch
      INTERNAL DIAMETER = 1.2154771inch       INTERNAL DIAMETER = 2.3081429inch
      JACK STROKE = 2.5658706feet
----------------------------------------------------------------------------
                 TYPE OF BRAKING SYSTEM......   DISC
============================================================================
TYPE   CON      FOR CONTINUE
>CON
 -TYPE THE OPTION AS INDICATED   BELOW
----------------------------------------------------------------------------
          OPTION                       SHORT FORM TO BE TYPED
-----------------------------------------------------------------------------

          DESIGN COMPLETELY ACCEPTABLE                     OK   <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                    ALTER   <THAT DESIGN NO >

          FURTHER SEARCH DESIRED                         SEARCH < XX >

          A NEW DESIGN DESIRED                           NEW    <NEW DESIGN NO>
==========================================================================

(QUESTION PLEASE TYPE YOUR OPINION NOW) >SEARCH XX

=============================================================================
              OLD DESIGN DETAIL
=============================================================================
          DESIGN NO =              DS2

          PURPOSE OF THE A/C              A4
          WEIGHT OF THIS A/C  =            16500

LANDING GEAR TYPE     PN

LANDING LEG TYPE      RETRACTABLE

---------------------------------------------------------------------------
LOCATION DETAIL ...
              WHEEL BASE = 12.768941               WHEEL TRACK = 10.368749
----------------------------------------------------------------------

              AUX-WHEEL DETAIL
              ...................
    PRESSURE  = 101.66666  psi                     TYRE DIA = 18.0  incns
     TYRE WIDTH = 5.6200000  incns                          RIM DIA = 8.0
    AXEL DIA = 1.3329111 WHEEL FLANGE THICKNESS = 0.22893568
    NUMBER OF BOLTS = 8     DIAMETER OF BOLT = 0.34813969incn
    WEB THICKNESS = 0.22893568     SHOCK ABSORBER = PNUEMATIC
    HEIGHT OF LEG = 4.1666666feet
    DETAILS OF LEG ====
    EXTERNAL DIAMETER =1.1313689inch     INTERNAL DIAMETER =0.69960466inch
    ASCESSORIES DETAILS ======
    BRACE ONE =====                     BRACE TWO =====
    LENGTH = 23.745074inch               LENGTH = 38.489717inch
    EXTERNAL DIAMETER = 0.90849655inch     EXTERNAL DIAMETER = 1.2932524inch
    INTERNAL DIAMETER = 0.45424827inch     INTERNAL DIAMETER = 0.86259940incl
    JACK STROKE = 2.2674880feet

TYPE   CON      FOR CONTINUE >CON
CON
----------------------------------------------------------------------

              MAIN WHEEL DETAIL
              .........................

    PRESSURE = 74.842103   psi                    TYRE DIA = 32.199995  inchs
     TYRE WIDTH = 9.1000000  incns                         RIM DIA = 15.5
    AXLE DIA = 2.6550889  inchs       WHEEL FLANGE THICKNESS = 0.16928348
    NUMBER OF BOLTS = 12     DIAMETER OF BOLT = 0.34023525inch
    WEB THICKNESS = 0.16928348     SHOCK ABSORBER = OLEO-PNUEMATIC
    HEIGHT OF LEG = 4.3541666feet
    DETAILS OF LEG ====
    EXTERNAL DIAMETER =2.8891400inch     INTERNAL DIAMETER =1.7623753inch
    ASCESSORIES DETAILS ======
    BRACE ONE =====                     BRACE TWO =====
    LENGTH = 31.904328inch               LENGTH = 43.555356inch
    EXTERNAL DIAMETER = 2.4309545inch     EXTERNAL DIAMETER = 3.4604842inch
    INTERNAL DIAMETER = 1.2154771inch     INTERNAL DIAMETER = 2.3081429incn
    JACK STROKE = 2.5658706feet
---------------------------------------------------------------------------
              TYPE OF BRAKING SYSTEM......   DISC
===========================================================================

TYPE   CON      FOR CONTINUE >CON

 TYPE THE OPTION AS INDICATED   BELOW
---------------------------------------------------------------------------
          OPTION                       SHORT FORM TO BE TYPED
-----------------------------------------------------------------------------
```

```
          DESIGN COMPLETELY ACCEPTABLE                          OK   <THAT DESIGN NO>

DESIGN ACCEPTABLE AFTER ALTERATION                          ALTER   <THAT DESIGN NO >
          FURTHER SEARCH DESIRED                              SEARCH < XX >
          A NEW DESIGN DESIRED                                NEW    <NEW DESIGN NO>
============================================================================

(QUESTION PLEASE TYPE YOUR OPINION NOW) >ALTER DS2
PLEASE TYPE A NEW DESIGN NO ....................>DS5

OLD DESIGN PARAMETERS ARE LISTED BELOW . GIVE OPENION BY TYPING   change  OR
 no
----------------------------------------------------------------------------
       name of the parameter                old value            opinion/newvalue
----------------------------------------------------------------------------
      FRICTION-COEF  GROUND                      0.44999999                 >NO
      % WEIGHT ACTING ON AUX-WHEEL                    12.0                    >CHANGE
PLEASE TYPE NEW VALUE ......                    >15.0
       CG VALUE OF THE A/C                       7.8999999                  >NO
       ASPECT-RATIO VALUE                        7.0                   >NO
      STALLING VELOCITY OF A/C                        50.0                    >CHANGE
PLEASE TYPE NEW VALUE OF VELOCITY ....                        >60.0
     FRICTION-COEF OF BRAKING MATERIAL                       0.35000000
>NO
 HEIGHT OF LEGS AT FORE AND AFT LOCATIONS        4.0    4.5           >NO
     TYPE OF LANDING GEAR                       PN                  >NO
        BRAKING SYSTEM                          DISC                   >NO

 ................................................
DESIGN WILL BE DONE FOR NOSEWHEEL-TYPE
........................................

------------------------------------------------

     UNDERCARRIAGE LOCATION DETAILS
FORE LOCATION                8.6828800   feet
AFT LOCATION                 1.5322729   feet
WHEEL BASE                   10.215152   feet
WHEEL TRACK                  10.734705   feet
-------------------------------------------------

MEDIUM CLASS AC

********************
PARTS DESIGN
********************

               DESIGN OF AUX-WHEEL
               ====================

AUX-WHEEL PRESSURE WILL BE CALCULATED

AUX-WHEEL TYRE SELECTION
          NUMBER OF TYRES IN AUX-WHEEL 1.0

STATIC LOAD ON AUX-WHEEL 3000.0

PRESSURE FINAL =  101.66666

AUX-WHEEL  DETAILS
                  DIAMETER OF TYRE        18.0
                  TYRE WIDTH               5.6200000
                   WHEEL RIM DIAMETER     8.0
               ---------------------------------
               DETAILED DESIGN OF AUX-WHEEL PARTS
               --------------------------------
WHEEL WILL BE DESIGNED AS MODERN SPLIT TYPE WHEEL
FINDING AXLE DIA
HOLLOW AXLE OF OUTER DIA  1.4357282
FLANGE THICKNESS = 0.22893568

DESIGNING FASTENING BOLTS
MATERIAL USED OPEN-HEARTH NICKEL STEEL

NUMBER OF BOLTS 8.0
DIA OF BOLT 0.34813969

               FINDING MAXIMUM STRESSES IN WEB OF AUX-WHEEL
               --------------------------------------------
ASSUMING THICKNESS OF WEB EQUALS TO THICKNESS OF FLANGE
          STRESSES CALCULATED AS
                         MAXIMUM RADIAL STRESS -5696.0610
                         MAXIMUM TANGENTIAL STRESS 22442.354
                         MAXIMUM SHEAR STRESS 908.22345

-------------------------------------------------
STRESSES CALCULATED ARE WITH IN THE LIMITS
THICKNESS OF WEB OF AUX-WHEEL 0.22893568
-------------------------------------------------

CHECKING ABOVE DESIGNED THICKNESS FOR A TORQUE

MAXIMUM SHEAR STRESS DUE TO PURE TORQUE 2395.9222

ABOVE CALCULATED SHEAR STRESS IS WITH IN THE LIMITS
FINAL WEB THICKNESS  0.22893568 inch

               DESIGN OF AUX-WHEEL LEG
               =======================

HEIGHT OF AUX-WHEEL LEG 4.1666666

PNUEMATIC TYPE OF SHOCK ABSORBER
SHOCK ABSORBER TRAVEL 0.79895253 FT

ANALYSING THE LANDING LEG

OPTIMAL WEIGHT DESIGN OF MAIN VERTICAL MEMBER STARTS
----------------------------------------------------

(QUESTION WHAT IS VALUE OF PENALTY PARAMETER) >1.0

(QUESTION WHAT IS VALUE OF EXPONENT) >2.0

(QUESTION WHAT IS VALUE OF CONSTANT) >10.0

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 0.61878094
          INTERNAL DIAMETER 0.36994437

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 0.85339551
          INTERNAL DIAMETER 0.53849257

DESIGNED DIMENSIONS
          EXTERNAL DIAMETER 1.1928144
          INTERNAL DIAMETER 0.72761680

====================================================

DESIGNED DIMENSIONS OF MAIN VERTICAL MAMBER IN inch
                         EXTERNAL DIAMETER  1.1928144
                         INTERNAL DIAMETER  0.72761680
====================================================

DESIGNING ASCESSORIES OF LANDING LEG
====================================

               DESIGNED DIMENSIONS OF CE
                         INTERNAL DIAMETER 0.50786501
                         EXTERNAL DIAMETER 1.0157300
               DESIGNED DIMENSIONS OF ED
                         INTERNAL DIAMETER 0.96441544
                         EXTERNAL DIAMETER 1.4459002
```

```
DESIGNED JACK-STROKE 2.2674881 FEET
                    DESIGN OF MAIN-WHEEL
                    =====================

MAIN-WHEEL PRESSURE WILL BE CALCULATED

MAIN-WHEEL TYRE SELECTION
             NUMBER OF TYRES IN MAIN-WHEEL 2.0

STATIC LOAD ON MAIN-WHEEL 7012.5

PRESSURE FINAL =  72.236842

MAIN-WHEEL  DETAILS
                       DIAMETER OF TYRE          32.199995
                       TYRE WIDTH                 9.1000000
                        WHEEL RIM DIAMETER       15.5

                    ----------------------------------
                    DETAILED DESIGN OF MAIN-WHEEL PARTS
                    ----------------------------------
WHEEL WILL BE DESIGNED AS MODERN SPLIT TYPE WHEEL

FINDING AXLE DIA

HOLLOW AXLE OF OUTER DIA  2.6245983
FLANGE THICKNESS = 0.17731269

DESIGNING FASTENING BOLTS
MATERIAL USED OPEN-HEARTH NICKEL STEEL

NUMBER OF BOLTS 12.0
DIA OF BOLT 0.34821055
                    FINDING MAXIMUM STRESSES IN WEB OF MAIN-WHEEL
                    ---------------------------------------------
ASSUMING THICKNESS OF WEB EQUALS TO THICKNESS OF FLANGE

              STRESSES CALCULATED AS
                               MAXIMUM RADIAL STRESS -8967.7735
                               MAXIMUM TANGENTIAL STRESS 28032.034
                               MAXIMUM SHEAR STRESS 3300.6741

-------------------------------------------------------
STRESSES CALCULATED ARE WITH IN THE LIMITS
THICKNESS OF WEB OF MAIN-WHEEL 0.17731269
-------------------------------------------------------

CHECKING ABOVE DESIGNED THICKNESS FOR A TORQUE

MAXIMUM SHEAR STRESS DUE TO PURE TORQUE 9589.2232

ABOVE CALCULATED SHEAR STRESS IS WITH IN THE LIMITS
FINAL WEB THICKNESS  0.17731269 inch
                    DESIGN OF MAIN-WHEEL LEG
                    ========================

HEIGHT OF MAIN-WHEEL LEG 4.3541666

PLEASE GIVE YOUR WEIGHTAGE FOR THE FOLLOWING
SPRING CHARACTORS IN THE RANGE OF 1 TO 10 . 10 BEING MAXIMUM

  1  SIMPLICITY OF SHOCK ABSURBER
  2  WEIGTH OF SHOCK-ABSORBER
  3  EFFICIENCY OF ABSORBER
  4  RELIABILITY OF ABSORBER
(QUESTION TYPE YOUR ANSWERS WITH A BLANK SEPERATING THEM) >6 7 8 4

FOR MAIN WHEEL OLEO-PNUEMATIC SHOCK ABSORBER IS  USED

SHOCK ABSORBER TRAVEL 0.69474133 FT

ANALYSING THE LANDING LEG


OPTIMAL WEIGHT DESIGN OF MAIN VERTICAL MEMBER STARTS
----------------------------------------------------

(QUESTION WHAT IS VALUE OF PENALTY PARAMETER) >1.0

(QUESTION WHAT IS VALUE OF EXPONENT) >2.0

(QUESTION WHAT IS VALUE OF CONSTANT) >10.0
```

```
)ESIGNED DIMENSIONS
          EXTERNAL DIAMETER 1.5929794
          INTERNAL DIAMETER 1.0957468

)ESIGNED DIMENSIONS
          EXTERNAL DIAMETER 1.7593199
          INTERNAL DIAMETER 1.1116438

)ESIGNED DIMENSIONS
          EXTERNAL DIAMETER 2.0831270
          INTERNAL DIAMETER 1.2290449

)ESIGNED DIMENSIONS
          EXTERNAL DIAMETER 3.0110857
          INTERNAL DIAMETER 1.8619650

====================================================

)ESIGNED DIMENSIONS OF MAIN VERTICAL MAMBER IN inch
                         EXTERNAL DIAMETER  3.0110857
                         INTERNAL DIAMETER  1.8619650
====================================================


)ESIGNING ASCESSORIES OF LANDING LEG
====================================

               DESIGNED DIMENSIONS OF CE
                         INTERNAL DIAMETER 1.1945792
                         EXTERNAL DIAMETER 2.3891585
               DESIGNED DIMENSIONS OF ED
                         INTERNAL DIAMETER 2.2684585
                         EXTERNAL DIAMETER 3.4009872


)ESIGNED JACK-STROKE 2.5658706 FEET

               DESIGN OF BRAKES
               =================

KINETIC ENERGY THAT HAS TO BE ABSORBED BY BRAKES IS 712800.0

               FINDING FORCE REQUIRED TO BRAKE STOP THE VEHICLE AFTER LANDING

....................................
SYSTEM RATING FOR BRAKE TYPES
................................

-----------------------------------------------------------------------------
   BRAKE TYPE               SYS.RATING VALUE                SHORT FORM
-----------------------------------------------------------------------------

   FOR THE SYSTEM TO CONTINUE ITS OWN DESIGN               CON

   SHOE BRAKE                1.9999997                         SHOE

   DRUM BRAKE                0.99999980                         DRUM

   DISC BRAKE                80.0                              DISC

   NO BRAKING                0.99999990E-1                         NO-BR

   PARACHUTE BRAKE           0.99999990E-1                     PARA
-----------------------------------------------------------------------------

NO OF FRICTION SURFACES IS   1
NO OF FRICTION PLATES   1

YES
Should I try for another answer (Y/N):>N

OK
<I0>RECORDFILE

RECORD FILE DSK: SS1 CLOSED 06-FEB-88 21:16:01
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==============================================================
          DESIGN DETAIL OF UNDER CARRIAGE
==============================================================
          DESIGN NUMBER -----------  DS5
--------------------------------------------------------------
           PURPOSE OF THE AIRCRAFT -----  A4
--------------------------------------------------------------
          WEIGHT OF THE A/C -----  16500
          TYPE OF LANDING GEAR ----  PN
          TYPE OF LANDING LEG ----- RETRACTABLE  TYPE
--------------------------------------------------------------
          LOCATION DETAILS
--------------------------------------------------------------
          WHEEL BASE ------  10.215152 feet
          WHEEL TRACK -----  10.734705 feet
==============================================================
           AUXILIARY LEG UNIT DETAILS ......
==============================================================
           AUXILIARY WHEEL DETAILS.......
--------------------------------------------------------------
           AUX-WHEEL PRESSURE --- 101.66666  psi
           TYRE DIAMETER  ---- 18.0  inches
           TYRE WIDTH ----     5.6200000  inches
           RIM DIAMETER -----  8.0  inches
           AXLE DIAMETER ---- 1.4357282  inches
           NUMBER OF BOLTS ------ 8
           DIAMETER OF BOLT ------ 0.34813969  inches
           WEB THICKNESS ----- 0.22893568   inches
--------------------------------------------------------------
           AUXILIARY WHEEL LEG DETAILS.........
--------------------------------------------------------------
           SHOCK ABSORBER ---- PNUEMATIC
           HEIGHT OF LEG -----  4.1666666feet
           EXTERNAL DIAMETER ---- 1.1928144  inches
           INTERNAL DIAMETER ----0.72761680  inches
           ASCESSORIES DETAILS -----
           BRACE ONE ---
                    LENGTH ---- 23.745075  inches
                    EXTERNAL DIAMETER ----1.0157300  inches
                    INTERNAL DIAMETER ----0.50786501  inches
           BRACE TWO ----
                    LENGTH ----  38.489719  inches
                    EXTERNAL DIAMETER ----  1.4459002  inches
                    INTERNAL DIAMETER ----  0.96441544  inches
           JACK STROKE ----  2.2674881feet
           RIM FLANGE THICKNESS -- 0.22893568  inches
==============================================================
               MAIN LEG UNIT DETAILS .....
==============================================================
           MAIN WHEEL DETAILS......
--------------------------------------------------------------
           MAIN WHEEL PRESSURE ----  72.236842  psi
           TYRE DIAMETER ----  32.199995   inches
           TYRE WIDTH ----  9.1000000  inches
           RIM DIA OF THE MAIN WHEEL ----  15.5  inches
           AXLE DIA OF THE MAIN WHEEL ----  2.6245983  inches
           NUMBER OF BOLTS -----  12
           DIAMETER OF BOLT ----  0.34821055  inches
           WEB THICKNESS ----  0.17731269  inches
--------------------------------------------------------------
          MAIN WHEEL LEG DETAILS ------
--------------------------------------------------------------
           SHOCK ABSORBER ----  OLEO-PNUEMATIC
           HEIGHT OF LEG ----4.3541666feet
           EXTERNAL DIAMETER ----  3.0110857  inches
           INTERNAL DIAMETER ----  1.8619650  inches
           ASCESSORIES DETAILS ----
           BRACE ONE ----
                    LENGTH ----  31.904328  inches
                    EXTERNAL DIAMETER ----  2.3891585  inches
                    INTERNAL DIAMETER ----  1.1945792  inches
           BRACE TWO ----
                    LENGTH ----  43.555356  inches
                    EXTERNAL DIAMETER ----  3.4009872  inches
                    INTERNAL DIAMETER ----  2.2684585  inches
           JACK STROKE ----  2.5658706  inches
           FLANGE THICKNESS OF THE RIM ----0.17731269  inches
--------------------------------------------------------------
           TYPE OF THE BRAKEING SYSTEM ---  DISC ---
 =============================================================
                    ......END OF DETAILS .....
==============================================================

NIL
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Th.
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